THE JOURNAL

OF THE

ROYAL AERONAUTICAL SOCIETY

(FOUNDED 1897 in succession to the ANNUAL REPORTS)

Edited for the Council by J. LAURENCE PRITCHARD, Honorary Fellow

No. 159 MARCH, 1924 VOL. XXVIII

NOTICES

Election of Members

The following Members were elected at a Council Meeting held on February 12th:—

Fellow.—Professor J. H. Parkin.

Associate Fellows.—Flight Lieut. N. Comper, A. A. Quayle and A. H. Leak.

Students.—B. Howard, G. Lyon, R. J. Moffett and R. W. Symmons.

Associate Member.—R. Michaelis.

Foreign Member.—R. T. Hurley.

Annual General Meeting

Voting members should have already received through the post formal notice that the Annual General Meeting will be held in the Library at 5.0 p.m., on Thursday, March 27th. They are reminded that nominations for election to the Council must be received by the Secretary not later than noon on the 6th of this month, and notification of subjects to be brought up for discussion not later than noon on the 13th.

The Council's Annual Report and Balance Sheet are published elsewhere in this issue.

Wilbur Wright Lecture

The Council have nominated Lieutenant-Colonel H. T. Tizard, A.F.C., Fellow, to deliver the annual Wilbur Wright Memorial Lecture. Details as to the date and subject of the lecture will be announced later.

Journal

The following numbers of the Journal are out of stock, though constant requests for them are being received. Members who may have copies of any of them which they do not wish to keep are asked kindly to forward them to the Secretary:—

No. 82, April, 1917.	No. 109, Jan., 1920.
No. 95, Nov., 1918.	No. 111, Mar., ,,
No. 96, Dec., ,,	No. 112, April, ,,
No. 97, Jan., 1919.	No. 115, July, ,,
No. 107, Nov., ,,	No. 138, July, 1922.

Forthcoming Arrangements

Thursday, March 6, 5.30 p.m.—*Major Tucker, "Sound Reception."

Tuesday, March 11, 5.30 p.m.—Council Meeting.
8.0 p.m.—SCOTTISH BRANCH.—Capt. W. H. Sayers, "Gliders."

Wednesday March 12, 8.30 p.m.—CAMBRIDGE UNIVERSITY AE.S.—Major J. H. Ledeboer, "Safety Precautions in Aeroplanes."

Thursday, March 20, 5.30 p.m.—*Mr. W. S. Farren, "The Work of the Aeronautical Research Committee's Panel on Scale Effect."

Thursday, March 27, 5.0 p.m.—**Annual General Meeting.**

Thursday, April 3, 5.0 p.m.—*The Master of Sempill, "The British Aviation Mission to the Imperial Japanese Navy."

* At the Royal Society of Arts, John Street, Adelphi.

W. LOCKWOOD MARSH, *Secretary.*

ROYAL AERONAUTICAL SOCIETY

59TH ANNUAL REPORT OF THE COUNCIL, 1923-1924

Council

Chairman.—Lieutenant-Colonel A. Ogilvie, C.B.E.

Vice-Chairman.—Professor L. Bairstow, C.B.E., F.R.S.

Brigadier-General R. K. Bagnall-Wild, C.M.G., C.B.E., Mr. Griffith Brewer, Wing Commander T. R. Cave-Browne-Cave, C.B.E., R.A.F., Sir Mackenzie D. Chalmers, K.C.B., C.S.I., Mr. C. R. Fairey, C.B.E., Mr. H. P. Folland, Squadron Leader R. M. Hill, M.C., A.F.C., Professor C. F. Jenkin, C.B.E., Professor B. Melvill Jones, A.F.C., Lieutenant-Colonel J. T. C. Moore-Brabazon, M.C., M.P., Mr. J. D. North, Lieutenant-Colonel M. O'Gorman, C.B., Professor A. J. Sutton Pippard, Mr. J. L. Pritchard, Colonel the Master of Sempill, A.F.C., Major R. V. Southwell, Lieutenant-Colonel H. T. Tizard, A.F.C., Major H. E. Wimperis, O.B.E.

Hon. Treasurer.—Mr. A. E. Turner.

Hon. Librarian.—Mr. J. E. Hodgson.

The chief event since the Council's last report has been the organisation by the Society's staff of the International Air Congress, London, 1923, by arrangement with the Committee of the Congress. The Council feel that this has resulted in a wider dissemination of knowledge of the Society's activities which cannot fail to have beneficial results.

Library

A number of further additions to the Library of valuable early books has been made from the generous grant of the Carnegie United Kingdom Trustees, practically the whole of which has now been expended.

During the last few months, Mr. J. E. Hodgson, who has kindly agreed to act as Honorary Librarian, has been re-arranging and re-cataloguing the Library, which will result in its having considerably increased value for reference purposes.

Through the kindness of various firms and individuals the Society's collection of lantern slides has also been considerably augmented during the year. This collection is now in great demand by members, a large number of slides being constantly out on loan.

Membership

The position regarding the membership is given in the following table :—

Membership at 1st January, 1923		886
Resigned	37	
Deceased	3	
	—	40
		846
New Members elected		34
Membership at 1st January, 1924		880

Awards

The Silver Medal of the Society, given annually for the paper deemed by the Council to be the best published in the Journal during the year, was awarded for the year 1922 to Lieutenant-Colonel E. W. Stedman, O.B.E., Fellow, for his paper on "Some Technical Aspects of Aviation in Canada."

The Pilcher Memorial Prize for Students was awarded to Mr. A. P. Rowe for his paper on "Aerial Navigation."

The first award of the R.38 Memorial Prize was divided between Mr. R. Jones for his paper on "The Aerodynamical Characteristics of the Airship as Deduced from Experiments on Models with Application to Motion in a Horizontal Plane," and Lieutenant-Colonel V. C. Richmond and Major G. H. Scott for their joint paper on "A Detailed Consideration of the Effect of Meteorological Conditions on Airships," the amount being increased from 25 guineas to 40 guineas, and divided between the authors of the two papers.

Associate Fellowship Examination

The second examination for Associate Fellowship was held in the Library on September 24th and 25th, when three candidates were successful. The papers set were published in the December issue of the Journal.

Journal

The Council are again able to record an improvement in the circulation of the Journal among non-members of the Society, the number of annual subscriptions having increased by a further 60 per cent. during the year. Mr. J. L. Pritchard continues to render invaluable services as Editor, and has again generously remitted his fees as a donation to the Society's funds. The Council feel that he is greatly to be congratulated on the increasingly high standard of the papers published.

Lectures

The Eleventh Wilbur Wright Memorial Lecture was read on May 31st, when Dr. Joseph S. Ames contributed a most valuable paper on "The Relationship between Aeronautic Research and Aircraft Design."

The full programme of lectures during the present session is as follows:—

1923.

Oct. 4.—Lieut.-Colonel A. Ogilvie, "Gliders and Light Planes."

,, 18.—Squadron Leader R. M. Hill, "The Manœuvres of Inverted Flight."

Nov. 1.—Major Wimperis, "Some Recent Developments in Aircraft Instruments."

,, 15.—Mr. H. R. Ricardo, "The Thermodynamics of Aircraft Engines."

,, 29.—Major R. H. Mayo, "The Development of High Speed Aircraft."

1924.

Jan. 10.—Dr. Aitchison and Mr. North, "Materials from the Aeronautical Point of View."

,, 24.—Dr. J. E. Ramsbottom, "Dopes and Fabrics."

Feb. 7.—Squadron Leader R. B. Maycock, "Airmanship at Sea."

,, 21.—Mr. H. Hamshaw Thomas, "Some Features in the Present Position of Aerial Photographic Survey."

Mar. 6.—Major Tucker, "Sound Reception."

,, 20.—Mr. W. S. Farren, "The Work of the Aeronautical Research Committee's Panel on Scale Effect."

Apr. 3.—Colonel the Master of Sempill, "The British Aviation Mission to the Imperial Japanese Navy."

Honorary Treasurer

The Council desire again to record their grateful thanks to Mr. A. E. Turner for continuing to act as Honorary Treasurer.

Staff

The Council have pleasure in recording their great appreciation of the services of the Staff during the year.

AERIAL (The Royal

Balance Sheet,

	£ s. d.	£ s. d.
To *Nominal Capital*—		
Divided into 20 Shares of 1/- each and 999 Shares of £1 each ...	1000 0 0	
,, *Capital Issued and Paid Up*—		
19 Shares of 1/- each		0 19 0
,, *Sundry Creditors*		1129 18 2
,, *Subscriptions Received in Advance*		45 7 0
,, *Carnegie U.K. Trust*—		
Grant for Purchase of Books		500 0 0
Expended 1922	355 13 3	
,, 1923, *per contra*	100 3 5	
	455 16 8	
,, *Reserve Fund*—		
Entrance Fees and Life Compositions of present Members, as at 31st December, 1922	2651 0 0	
Receipts for year to 31st December, 1923	30 9 0	
	2681 9 0	
Deduct—Income and Expenditure Account Deficiency at 31st December, 1922 ... ... £1684 10 8		
Add—Excess of Expenditure over Income for the year to 31st December, 1923 ... ... 138 13 8		
	1823 4 4	858 4 8
		£2534 8 10

We report to the Shareholders that we have examined the books of the Society and have of the value put upon the outstanding subscriptions. Subject to this remark, we are of opinion of the Society's affairs according to the best of our information and the explanations given to us

3, FREDERICK'S PLACE, E.C.2.
February 18th, 1924.

Income and Expenditure Account

Dr.	£ s. d.
To Office Rental, Lighting and Insurance	329 17 7
,, Salaries	1050 19 4
,, Printing, Stationery, Etc.	28 13 10
,, Postage and Messengers	56 17 5
,, Library Expenses	2 18 5
,, Office Expenses	62 15 1
,, Exhibitions and General Meetings	99 0 0
,, Journals, Pamphlets, Etc.	452 19 2
,, Audit Fee	15 15 0
,, Subscriptions Written Off	68 1 9
,, House Duty	11 5 0
,, Examination Expenses	2 2 6
,, Expenses in connection with Students' Section...	0 5 11
,, Honorarium to Editor of JOURNAL	10 10 0
	£2192 1 0

Journal and Sundry

	£ s. d.
To Stock, 31st December, 1922...	368 0 5
,, Refunds	1 16 4
,, Purchases of Books (Old Journals)	9 13 2
,, Law Costs *re* Advertising...	2 2 0
,, Printing of Journal, Blocks, etc.	992 18 5
,, Binding of Journal	4 12 6
,, Postage of Journal	70 8 3
,, Printing Sundry Publications	16 5 0
,, Printing Advance Proofs	22 10 6
	£1488 6 7

SCIENCE, LIMITED
Aeronautical Society).
31st December, 1923.

	s. d.	£ s. d.
By *Office Furniture, Printed Books, Bindings, Stationery, Old Prints, etc.*, as at 31st December, 1922 (including Carnegie Grant—£355 13s. 3d)	686 9 11	
Add—Purchased during year	100 3 5	
		786 13 4
,, *Stock of* JOURNALS, *etc.*		429 16 1
,, *Stock of Stationery*...		23 13 0
,, *Sundry Debtors, including Subscriptions owing*		260 9 11
,, *Investments at Cost*—		
£100 5% National War Bonds	100 0 0	
£783 6s. 0d. 5% War Loan Inscribed Stock, 1924/47	725 13 6	
		825 13 6
,, *Cash at Bank and in Hand*—		
At Bank	201 17 10	
In Hand	6 5 2	
		208 3 0
		£2534 8 10

obtained all the information and explanations we have required. We are not in a position to judge that such Balance Sheet is properly drawn up so as to exhibit a true and correct view of the state and as shown by the books of the Society.

(Signed) PRICE, WATERHOUSE & CO.

for the Year Ending 31st December, 1923.

Cr.	£ s. d.
By Annual Subscriptions	1821 2 4
,, Interest of Investments and Deposit	44 16 2
,, International Air Congress	176 18 10
,, Donation from Mr. J. L. Pritchard	10 10 0
,, Balance, being Excess of Expenditure over Income	138 13 8
	£2192 1 0

Publications Trading Accoun

	£ s. d.
By Advertising Revenue	104 0 0
,, Sale of Journals	458 12 11
,, ,, Journal Cases	3 19 0
,, ,, Advance Proofs	8 12 9
,, ,, Sundry Publications	30 6 8
,, Stock, 31st December, 1923	429 16 1
,, Balance, loss carried to Income and Expenditure Account	452 19 2
	£1488 6 7

PROCEEDINGS

FIFTH MEETING, 59TH SESSION

A meeting of the Royal Aeronautical Society was held at the Royal Society of Arts, John Street, Adelphi, London, on Thursday, November 29th. Colonel A. Ogilvie (Chairman of the Society) presided, and Major Robert Mayo read a paper on "The Development of High Speed Aircraft."

The CHAIRMAN, in introducing Major Mayo, said it was originally intended that Squadron Leader Maycock should read a paper that evening, but he had been unable to prepare it in time, and Major Mayo had stepped into the breach.

Major MAYO then read his paper :—

THE DEVELOPMENT OF HIGH-SPEED AIRCRAFT

Introduction

I must apologise for the many shortcomings of this paper and plead in excuse that it has been very hurriedly prepared. When I was asked at short notice to write a paper in place of Squadron-Leader Maycock's, I somewhat rashly undertook to do so, but it has proved a formidable task in the very limited time available.

The recent brilliant achievements of the Americans in the development of high-speed aircraft led me to think that the subject would be an interesting one for a paper, but I realise only too clearly that I have been unable to do it justice in the short time at my disposal.

From the earliest days of flying the attainment of high speed has been one of the great incentives to designers and one of the greatest desires of pilots.

The development of high-speed motor-cars is a means to an end, but the development of high-speed aircraft is an end in itself. Both in the military and commercial spheres the attainment of maximum possible speed has been and will continue to be an objective of primary importance.

Early Development

I propose in the first place to make a cursory survey of the history of high-speed machines, starting not from the earliest days of flying but from the time when the aeroplane had so far developed as to make competitive racing practical and interesting. I think it will be convenient to deal with land-type machines first and later to give a brief review of the position in regard to seaplanes.

The first landmark in the development of the high-speed aeroplane may be said to have been the establishment of the International Gordon-Bennett Race in 1909. The various military powers were of course watching progress before that date, but no nation was taking flying very seriously. In point of fact, no military authority did take it seriously until the purely civil investigation of pioneers had gone a long way to developing the high-speed machine.

The first Gordon-Bennett race was won by Glenn Curtiss, the American pioneer. This victory, though not in itself important—for the machine was perhaps not the fastest at that time—is interesting in view of later developments. The firm established by Curtiss was to become the greatest American aircraft firm and was destined to achieve extraordinary distinction in the development of high-

speed aircraft. The efforts of this firm have culminated in the winning of the International Schneider Trophy Race for Seaplanes, the International Pulitzer Race at a speed of 243 m.p.h., and the subsequent establishment of a new world's record of 266.58 m.p.h., all of which have been achieved within the last two months.

I am not going to dwell on this early Curtiss effort. It is of the box-kite pusher type with everything exposed to the wind and no attempt at streamlining. Its speed of 47 m.p.h. was not bad considering that an engine of only 30 h.p. was used. It had a power loading of 18.3 lbs. per h.p. and a surface loading of only 2.02 lbs. per square foot.

It may be observed here that the success of the Curtiss in the Gordon-Bennett Cup of 1909 was the first and only success of a pusher machine in any international speed race. At the time of this race the tractor machine had already established itself as a type with great possibilities. Bleriot had flown the Channel and several tractor machines had been designed. Bleriot competed in the Gordon-Bennett and had the fastest time for a single lap, but just failed to beat Curtiss on the whole course. From then onwards the tractor machine became the predominant speed type, and it will be seen that once this type was firmly established, the progress in speed was very rapid.

The Bleriot machine was not exactly a model of careful streamlining and reduction of unnecessary head resistance. The front elevation shows a maze of parts of anything but streamline form. Bleriot retained his peculiar though effective under-carriage and engine mounting right up to the start of the war, but the enormous head resistance entailed soon left him far behind in the quest for speed. It is even surprising that the Gordon-Bennett of 1910 should have been won on a 70 Gnome Bleriot, for by that time other designs of tractor monoplane of obviously improved aerodynamic design had appeared. Still Bleriot's early appreciation of the merits of the tractor machine gave him a permanent place of distinction in the evolution of the modern high-speed aeroplane.

The tractor monoplane type held the field throughout those years of rapid development from 1910 to the war. The Gordon-Bennett was won in 1911 by the Nieuport monoplane with 100 h.p. Gnome engine at a speed of 79 m.p.h. This machine shows a marked improvement on the Bleriot in regard to streamlining of the fuselage and reduction of unnecessary external head resistance.

The Gnome Engines

The importance of the effect of the series of Gnome engines on the whole progress of aeroplane design can hardly be exaggerated. The original engine was the rated 50 h.p. giving an effective b.h.p. of about 45 at a weight of 3.8 lbs. per effective b.h.p. The subsequent Gnomes showed a progressive increase in power and reduction in weight per horse-power, the 160 Gnome giving about 145 effective b.h.p. at a weight of 2.7 lbs. per effective b.h.p. From the time of Bleriot's Channel crossing in 1909 onwards, design of high-speed aeroplanes began to crystallise round the Gnome engine. Each year brought a new Gnome of increased power and a new series of tractor monoplanes designed round the latest engine. Other types of engine were of course developed and employed on various types of aeroplane, but for high-speed machines only the latest Gnome was in the running.

Later on, new types of rotary engine were produced, but they were essentially based on the Gnome design. It was not until 1916, after two years of war with its intensive technical development of the aeroplane, that serious attempts were made to design a high-speed single-seater with a stationary engine, and then only because the ever-increasing military loads demanded a higher power

than could be supplied by any rotary engine of the day. The introduction of the Hispano Suiza engine struck the death knell of the rotary engine. A British rotary engine of greatly increased power—the B.R.2— was subsequently produced, but the fastest machines have always employed stationary engines from 1917 onwards. However, the Gnome engine had a profound influence on the design of high-speed aeroplanes, and by 1913 a very definite type of racing machine had been evolved. The Gordon-Bennett Race was won in 1912 by the Deperdussin monoplane fitted with the 140 Gnome, this machine showing the greatly improved speed of 105 m.p.h. Another Deperdussin fitted with the 160 Gnome engine won the Gordon-Bennett Race in the following year, achieving the remarkable speed of 125 m.p.h.

The designers of this machine paid very careful attention to streamlining and reduction of head resistance. The fuselage was of good streamline form, the nose being improved by means of a large propeller spinner. They also showed a shrewd appreciation of the gain in high speed to be obtained by sacrificing low speed. The chief characteristics were :—

Weight fully loaded ...	1,350 lbs.
Wing area	104 sq. ft.
Effective h.p.	145
Weight per sq. ft.	13 lbs.
Weight per h.p.	9.3 lbs.

French Ascendancy

Apart from Curtiss's success in the Gordon-Bennett of 1909, the evolution of the high-speed machine was entirely in the hands of the French until 1913, and the history of high-speed aeroplanes reflects the history of aeroplane development generally. The aeroplane was made possible in the first place by the patience and tenacity of the Wright brothers in their long scientific researches and experiments. The French were quick to perceive the immense value and possibilities of what the Wrights had achieved, and, taking up the new idea with characteristic enthusiasm and brilliance, developed the design of the aeroplane to an astonishing degree in those crowded years before the war. But gradually the British and Germans were picking up the threads of the new science and its importance was impressing itself upon them. At the start of the war, France was well ahead of any other nation in the technical development of the aeroplane, but we as a nation had woken up to the situation and had embarked on a vigorous policy of research which was to give us air supremacy as the war progressed. In the meantime America had lapsed into indifference, only to return to enthusiasm of unparalleled vigour under the stimulus of war. The development of the high-speed aeroplane exactly followed these lines. America won the first International Gordon-Bennett Speed Race in 1909 and then produced nothing more of outstanding merit until 1920, when the fruits of her great period of research and development began to be reaped. After the Gordon-Bennett Race of 1909, France won every international speed event of importance till 1914, and during this prolific period of French activity the essential evolution of the modern type from the original American type took place.

British Awakening

But in the meantime steady progress was being made in England. The tractor type had found early favour, for Mr. Roe employed it from the first. Although Mr. Roe's early machines, first the triplane and then the biplane, were not in any sense high-speed machines, they had an important effect on subsequent British high-speed design.

Mr. Roe's successful design was followed up by de Havilland's B.E.2, which, designed in 1911 and demonstrated in 1912, had so good a performance that the tractor biplane became firmly established in the minds of British designers as the best all-round type. This machine was not exactly perfect in streamlining and reduction of head resistance, but it was good enough to survive in generally the same form till the war was half-way through. However, the days when it was considered fast were short, for it was soon followed by new types greatly improved from the speed point of view.

The First Biplane "Scout"

In 1913 the B.S.1, designed at the Royal Aircraft Factory, appeared. This machine was a small tractor biplane fitted with the 100 h.p. Gnome engine. In it a serious effort was made to provide a fuselage of streamline form, with the engine well cowled in and the opening of the pilot's cockpit considerably reduced in size. Although this machine was not a success, owing to its having too small a rudder, it must be regarded as the original design of what was quickly established as the standard British type of high-speed machine. The S.E.2 was practically the B.S.1 rebuilt with a larger rudder and the 80 Gnome in place of the 100 Gnome.

The S.E.2 appeared in the autumn of 1913, about the same time as the Sopwith Tabloid. These two machines—though designed quite independently—were essentially of similar conception. Both machines were small biplanes of the single-bay type and their general lines were very similar. Their maximum speed was about 90 m.p.h.

In France the monoplane was the standard type for high-speed machines up to 1914, but from then onwards the biplane began to come into favour, and at the end of the war was almost universally employed for high-speed work. But it should be remarked here that although the tractor biplane was essentially a British type, the main credit for the early development of the high-speed machine should go to the French, who developed the streamline tractor fuselage. It should also be remarked that the biplane form was adopted in England almost entirely from strength considerations, and I think it is true to say that the monoplane was ruled out somewhat unreasonably on account of certain specific structural failures.

There are two other British pre-war machines which should be mentioned—the Bristol Scout and the S.E.4.

The Bristol Scout, which appeared in the spring of 1914, was essentially of similar type to the S.E.2 and the Sopwith Tabloid, and was fitted with the same engine, the 80 Gnome, but it contained two important differences and improvements. In the first place its undercarriage was of the simple V type, the elaboration of unnecessary skids being cut out. Secondly, its fuselage was considerably reduced in cross-sectional area. The general lines of the fuselage were by no means perfect, and the reduction in size may not in fact have had a great effect on the speed, but I think it is of importance in view of the tendency which the war produced to let the size of fuselage creep up unnecessarily. The fuselage of the modern American racing machines is reduced to the minimum possible compatible with the size of engine employed.

The S.E.4

The last of the British pre-war machines requiring mention is the S.E.4 of 1914, and I regard this machine as one of the really important landmarks in the history of high-speed flying. This machine was designed with the specific object

of attaining the highest possible speed compatible with safety in landing. It did in fact put up a speed of 130 m.p.h. over the speed course, but the value of this in comparison with the 125 m.p.h. of the Deperdussin with the same engine can only be appreciated when it is remembered that the wing loading and landing speed were vastly different. The Deperdussin was designed solely as a racing machine, and its loading of 13 lbs. per sq. ft. and landing speed of probably over 75 m.p.h. were inordinately high for those days. The S.E.4, on the other hand, had a wing loading of only 9 lbs. per sq. ft. and a landing speed of only 48 m.p.h., and it was for this reason a far more reasonable flying proposition than the Deperdussin.

The S.E.4 was based on the S.E.2 design, but the 160 Gnome was used instead of the 80 Gnome. Every effort was made to make the fuselage of as perfect a streamline form as possible, and drastic cuts were made in external resistance. An attempt was made to eliminate the resistance of the pilot's head and cockpit by making a streamline hump over the cockpit and covering in the pilot with a transparent cellon covering. The pilot declined to fly the machine with the covering on, so it was removed, and the final result was probably rather worse than if the pilot's head had stuck out of the fuselage in the ordinary way. However, this was only one of the features of the machine; there were a number of other new features, including the following :—(1) Use of wing flaps adjustable by pilot during flight for increasing lift for landing and reducing drag at high speeds. It was reckoned that this gave about an extra 5 m.p.h. at each end of the scale; (2) single-bay single-strut construction; (3) small tripod undercarriage; (4) gaps between control surfaces and fixed surfaces faired over; (5) wires fitted with streamline sheaths.

The speed range of this machine being 48 m.p.h. to 130 m.p.h., it was a big step forward in high-speed design. Its leading characteristics were :—

Total weight	...	...	1,540 lbs.
H.P. (effective)	...	...	145
Wing area ...	...	...	188 sq. ft.
Weight per h.p.	...	...	10.6
Weight per sq. ft.	...	...	9.0 lbs.

It is generally supposed that this machine was a failure owing to its high landing speed. This is not the case; after making a number of successful flights, it crashed after landing, but only owing to there being a balk of timber lying concealed in the long grass of the aerodrome. The machine was ahead of its time and was regarded by the authorities as too difficult for the average pilot. But it must be considered as representing the British standard of high-speed design attained in the pre-war era.

The British Research Period

I have given an indication of the remarkable progress in British high-speed design during the years 1911-14. The development in this direction is illustrative of the general progress made during this remarkable period. The evolution of the inherently stable aeroplane is another example of what was being achieved. What was the reason for these rapid and immensely important strides? It was that as a nation we were applying ourselves with extraordinary vigour to aerodynamical research, not only on the full scale but in the laboratory.

The work done at the National Physical Laboratory, at the Royal Aircraft Factory and other institutions, and at the various constructors' and experimenters' works and aerodromes during these critical years, was the basis on which our air supremacy during the later stages of the war was built.

I have now completed a very rough outline of the pre-war period of development of the high-speed machine; the progress made from 1909-14 is illustrated by the curves, which refer to the Gordon-Bennett winners, and it will be noticed how closely the speed and power curves follow each other.

The War Period

It would obviously be impossible within the limits of this paper to give more than a mere glimpse of the development which occurred during those four war years of intense aeronautical activity. To refer in detail to every important type of high-speed aeroplane produced would be out of the question, and I must content myself with trying to indicate the general tendency of design, illustrating my remarks by references to some of the outsanding types.

The first British machine to be applied as a fighting scout was the Bristol Scout, with a gun stuck on the top of the plane, exposed to the air and in a most awkward position for fighting purposes.

Then followed the D.H.2 and the F.E.8 pusher scouts, giving improved visibility and fighting qualities, with a maximum speed of about 90 m.p.h. They had a day of great success and then passed out because they were not fast enough. Thereafter no further effort was made to resuscitate the pusher type for speed purposes. There followed a series of tractor biplane scouts with rotary engines, carrying a greater and greater military load as the war proceeded, but showing a gradual tendency to improved performance. Of the British machines I would mention the Sopwith "Pup" (80 Le Rhone), the D.H.5 (110 Le Rhone) and the Sopwith "Camel" (130 Clerget), and of the French machines the Nieuport "Baby" (80 Le Rhone).

In 1916 one solitary monoplane appeared—the Bristol with 110 Le Rhone engine. This machine had the remarkable speed of 127 m.p.h. at 6,500ft., which was a long way ahead of that of any other military machine up to that date. In spite of its fine performance the machine was not considered suitable for work in France and was only used for service in the East. This was the only British monoplane produced during the war.

Another interesting machine was the Sopwith Triplane with 130 Clerget engine, which had a short but successful career as a fighter.

Of the German machines the outstanding single-seater fighter was the Fokker, but contrary to the general supposition at the time, this was not a fast machine. It had a fairly good climb, but the great feature which brought it such success

was its synchronised gun firing through the propeller. Apart from that it was no advance on French and British types.

In 1916 the whole situation in regard to speed machines began to change. New and much more powerful engines designed after the start of the war began to come forward. The more powerful British engines were applied in general to the larger types of aeroplane, and it was not until supplies of the French Hispano-Suiza engine were available that the water-cooled engine was seriously applied to the single-seater scout machine.

I do not propose to follow the rapid progress in the design of the larger-type machines which resulted, but mention should be made of the D.H.4 two-seater bombing and reconnaissance machine which appeared in 1916. This machine, fitted first with the 200 h.p. B.H.P. engine and later with the Rolls Royce Eagle engine, was a big step forward in aerodynamic design. It displayed a cleanness of line which was a great advance on any previous military machine, and in it further advances in the reduction of head resistance were made. One notable point was the elimination of duplicate wires, duplication of lift bracing being secured through the incidence wires. The speed of the B.H.P. machine with full load (117 m.p.h. at 6,500ft.) was better than that of any previous military machine (single-seater or otherwise) except the Bristol monoplane, while the 375 h.p. Rolls Royce Eagle VIII. machine had a speed of no less than 136.5 m.p.h. at 6,500ft. This was the fastest two-seater machine produced during the war.

The advent of the eight-cylinder Vee-type Hispano-Suiza engine—at first 150 h.p. ungeared and then 200 h.p. geared—produced new types of single-seater high-speed machines of the greatest importance. Since the introduction of this engine the water-cooled engine has been predominant for high-speed machines, and the progress of the water-cooled type has continued to be steady and rapid.

The French Spad machine was the first of the Hispano-Suiza scout machines, but the British S.E.5 was designed concurrently and appeared soon afterwards. There never was much difference between these machines in performance; both had the 150 Hispano at first and the 200 Hispano when it became available. The Spad had a good fuselage shape, the round section which had become standardised by the use of rotary engines being to a great extent preserved. External head resistance was somewhat unnecessarily increased by the introduction of intermediate struts in the wing structure. The S.E.5 had a rectangular-sectioned fuselage with a flat radiator in front. What the S.E.5 lost from the bad streamline form of its fuselage it probably more than gained by the smallness of its fuselage section.

The S.E.5 was followed by the Sopwith Dolphin, which had approximately the same speed but military advantages in other directions. Features of this were side radiators in place of the nose radiator with a generally improved streamline form of fuselage, and the placing of the pilot in a gap in the top centre section.

The Martynside F.4

But meanwhile the important Martinsyde F.3 employing the Rolls Royce Falcon engine had appeared. This machine passed through various stages, but finally passed into production as the F.4 with the 300 Hispano-Suiza engine—an enlarged and ungeared version of the 200 Hispano-Suiza. The Martinsyde F.4 was the fastest machine put into production in this country, and I think in any country during the war. Its speed was officially recorded as 144.5 m.p.h. at 6,500ft., which would mean, say, 147 at ground level. Its main characteristics were :—

Weight (loaded)	2,289 lbs.
H.P.	305
Wing area	329.5 sq. ft.
Weight per h.p.	7.5 lbs.
Weight per sq. ft.	6.95 lbs.

This machine had a fuselage of rather large section with a flat radiator nose. The general shape of the fuselage was of a fairly good streamline form, but it was distinctly less slender than one would have expected. A considerable sacrifice in top speed was made in order to obtain the slow landing speed of about 45 m.p.h. The secret of this machine's good performance was its light loading per horse-power, achieved by excellence of general structural and detail design.

Its maximum speed was more than three times its minimum speed, which is a very good figure taking into consideration that it was designed as a military machine and not merely as a racer. I take the Martinsyde F.4 as representing the highest standard of design of a high-speed machine achieved during the war.

As regards the German machines which appeared during the war, I do not think they were at any time as fast as the best Allied machines. They also used the rotary engine till about 1916, and then developed a series of designs employing various six-cylinder water-cooled engines. The Albatross showed a good appreciation of the importance of streamline form.

The Revival of the Rotary Engine

Before leaving the war period I ought to mention two things. Firstly, the revival of the rotary engine type single-seater scout, which occurred in 1918. The B.R.2 rotary engine, giving the greatly increased power of 230 h.p. at the attractive weight of 2.16 lbs. per h.p., appeared early in 1918, and the Sopwith Snipe was designed to take this engine. This machine was of great military value, and is still one of the standard machines with which our Air Force is equipped, but its speed (about 130 m.p.h.) was a little disappointing, having regard to the power and weight of the engine. But the fact is that a rotary engine of 200 or more horse-power does not pay; too much power is wasted in churning up air by the large cylinders. The Snipe was the last important attempt at a high-speed machine with a rotary engine, and it is unlikely that a rotary engine will ever again figure in the fight for high-speed honours.

The other important development at the end of the war was the introduction of the high power air-cooled radial engine. This type of engine offered exceptional possibilities in regard to low weight per h.p., but on the other hand it involved considerably increased head resistance. The balance of technical argument was in its favour, and it also had great advantages from the production point of view. The 340 h.p. A.B.C. Dragonfly engine was put into production on a large scale, but for various reasons it was not successful—at any rate, during the war. Therefore I do not propose to deal with the machines fitted with this engine, but I shall, of course, refer below to certain British air-cooled radial engines which have been successfully developed since the war.

Review of the War Period

In reviewing the war period development it at once strikes one that the progress made in regard to speed was surprisingly small. When it is remembered how vitally important speed was from the early stages till the end of the war, and how greatly the power and weight efficiency of the engines available increased, it is surely remarkable that the maximum speed attained should have been less than 20 m.p.h. above the pre-war standard. Full allowance must of course be made for the ever-increasing weight of military equipment which had to be carried and the extra resistance entailed by this equipment, but when all

such allowances have been made, I think it must be admitted that the progress made was not in proportion to the immense amount of designing effort put in. The reason for this lies, I think, in the fact that the war period was not a period of research, but a period of application of previously acquired knowledge. There was no time for pure research, and so the science of aerodynamics, which essentially depends on research (as any new science must), did not advance a great deal. But on the other hand the war period was one of intense activity in design and technical development generally, and in the struggle for air supremacy we were splendidly served by our great pre-war period of research.

The Post-War Period.

I have now to deal with the extraordinarily rapid development of high-speed aircraft which has occurred since the war. The post-war period is a depressing one from the British point of view, for whereas in 1918 we could justly claim to be ahead of any other nation in aeroplane design, we certainly could not make any such claim to-day.

For a brief period after the war there was a lull, and then the old pre-war international rivalry sprang up again. The old international competitions were revived, and they had naturally assumed a greater importance and interest than they had before the war. The first post-war Gordon-Bennett Race was in 1920, and it was won by France with the 300 Hispano-Suiza Nieuport Biplane. This machine was an improved version of the latest war type Nieuport single-seater fighter. The main characteristics were :—

Weight loaded	1,835 lbs.
Wing area	140 sq. ft.
H.P.	310
Weight per sq. ft.	13.1 lbs.
Weight per h.p.	5.9 lbs.

The official speed over the 300 km. course was 169 m.p.h.

This machine had a good streamline fuselage of slim section. A new feature was the Lamblin type radiator placed below the fuselage and enabling the fuselage to be given a nose of good streamline form.

The British hope in this race—the Martinsyde Semi-Quaver, which was an improved F.4 with smaller wings—failed through engine trouble.

The Beginning of American Supremacy

It was at this stage that America loomed up as a potential power in the struggle for aerial honours, for a team of three American machines was entered for this first post-war contest. The team suffered from various troubles such as engine failure, and did not do itself justice, but the careful and advanced design of these first racing machines was sufficient to indicate that America's great aerial effort, which started in 1917 and thereafter never slackened, was already bearing fruit. America had realised that when she started to build up her air forces in 1917 there was a lot of leeway to make up, and she had taken a far-sighted view of the situation. Providing for the immediate equipment of her forces with the best allied designs available, she proceeded to build up the finest technical and research organisation in the world. By dint of concentrated efforts and study, she picked up the threads in an amazingly short time, and by the end of the war was rapidly becoming a leading aerial power. The war ended before America had time to demonstrate the immense progress she had made, but with the slackening of French effort after the Armistice and the almost complete cessation of British effort, it was not long before America took the lead. Her post-war achievements in the design of high-speed aircraft are an index of her progress in all branches of aeronautical science, and this progress has been due,

not as is sometimes supposed to the expenditure of vast sums on her air services generally, but to a proper appreciation of the relative importance of research and experiment. I will now resume and conclude my summary of what has occurred in the development of high-speed aircraft, and the final stages will afford illustrations of the manner in which America has achieved her success.

Although the American effort in the Gordon-Bennett Race of 1920 was thwarted by mechanical troubles, it was only a few weeks later that the Verville-Packard machine won the first international race for the Pulitzer Trophy.

This machine, fitted with the 600 h.p. Packard engine, was practically identical with the machine sent to France for the Gordon-Bennett Race. It had a deep but generally well-shaped fuselage and single-strut single-bay wing construction, but was rather large for a racing machine, and appears to have derived its speed from its exceptionally powerful engine rather than from fineness of aerodynamic design.

Further French Successes

The French success in the Gordon-Bennett Race of 1920 won that cup outright for France, but a new international speed race for the Deutsch Cup was immediately established by the French. The first contest for this was to be held in the autumn of 1921, but throughout that year and the succeeding year there was the keenest rivalry between various French firms to establish new world's speed records over the kilometre course. The record went up by small advances to 194 m.p.h. at the end of 1920, and then to 205 m.p.h. in the autumn of 1921. The successive small advances were achieved mainly by boosting up the power of the 300 h.p. Hispano-Suiza engine and by minor improvements in streamlining. The big jump to 205 m.p.h., however, was due to the introduction of the new type Nieuport—the Sesquiplan. Too much importance must not be attached to these records as speed over a kilometre has never been very accurately measured, and in any case it is always higher than the speed over a long course.

The celebrated Nieuport Sesquiplan appeared in the summer of 1921. This was practically a monoplane with the fairing over the axle used as an auxiliary lifting surface. In this machine the limit of perfection in streamlining of a fuselage for the 300 Hispano-Suiza engine appeared to have been reached, and the whole machine was designed with the utmost care with a view to reduction of head resistance. The weight per horse-power was reduced to 6.2 lbs., but on the other hand the loading per sq. ft. of surface was no less than 17.25 lbs., giving a landing speed of 75 to 80 m.p.h. The machine required very skilful piloting, but it got it and won the Deutsch Cup Race in 1921 at 175 m.p.h. This speed does not represent the full speed of the machine, however, as the pilot had practically a walk-over, the other competitors having been eliminated by various troubles. The same type of machine, after setting up new records over the measured kilometre, would have won the Deutsch Cup of 1922 but for engine trouble, for in the only completed lap Sadi Lecointe raised the record for 100 kilometres to 202 m.p.h. This race was won by a Nieuport biplane of essentially the same design as that of the 1920 Gordon-Bennett winner, but at the improved speed of 179.6 m.p.h.

But in the meantime America had been making steady progress in the design of racing machines. The American Government had appreciated the value of racing as a means of developing high speed qualities and had embarked on a policy of definite encouragement of and even participation in racing events. The Pulitzer race became a great annual contest between the American Navy and Army departments and the progress made under the stimulus of this perfectly healthy rivalry has been astounding. In 1921 the winner was the Curtiss Navy Racer fitted with the 400 h.p. Curtiss engine. This 12-cylinder Vee engine was

specially designed for high speed work and was made exceptionally compact with a view to reduction of head resistance.

The fuselage has a beautiful streamline form and does not appear to offer much scope for further improvement, while the general structure is also very clean. Two of the French Lamblin type radiators are employed. The principal characteristics were:—

Total weight	2,165 lbs.
Wing area	173 sq. ft.
H.P.	400
Weight per sq. ft. ...	12.5 lbs.
Weight per h.p.	5.4 lbs.

The speed recorded in the Pulitzer race was 176.7—a little better than that of the Sesquiplan in the Gordon-Bennett. In judging of the merit of this performaace, however, it must be borne in mind that the wing loading and landing speed were far lower than those of the Sesquiplan.

The 1922 Pulitzer race was another triumph for the Curtiss organisation. This time the army racer was the star turn, and the speed, 206 m.p.h., was nearly 30 m.p.h. greater than that of the 1921 winner. Seeing that the 1922 engine was being run at 25 h.p. less than the year before, this was a remarkable achievement. The main characteristics were:—

Total weight	1,950 lbs.
Wing area	131 sq. ft.
H.P.	375
Weight per sq. ft. ...	14.9 lbs.
Weight per h.p.	5.2 lbs.

The variations from the older type were:—Slightly reduced size of fuselage, reduced structure weight, reduced wing area, surface loading increased from 12.5 to 14.9 lbs. per sq. ft., and h.p. loading slightly reduced (from 5.4 to 5.2 lbs. per h.p.). But all these together only account for a small part of the total increase in speed. This increase was mainly due to the introduction of wing radiators in place of the Lamblin radiator hitherto used on all up-to-date racing machines. The wing radiator was not due to a sudden brain wave but the result of two or three years of patient and exhaustive research. It was not merely an ordinary radiator stuck in the wing, but a conversion of the actual smooth surface of the wing into the cooling surface for the engine. Head resistance entailed in the cooling system was thus almost entirely eliminated and by the skilful design employed this was done with practically no increase in weight. This most important development resulted in a gain in speed of nearly 20 m.p.h. It was one of the triumphs achieved by American research workers since the war. It is to be noted that the radiators used on these racing machines are not mere freaks—they are suitable for quantity production and are a sound and robust job.

Other improvements over the 1921 navy racer were N struts in the wing structure replaced by single I struts, Vee undercarriage struts replaced by single struts. Gaps between main and control surfaces covered with rubber strips, giving perfect continuity.

We now come to the 1923 Pulitzer Race which produced so extraordinary an advance on all previous designs. The winner of this race was again a Curtiss racer, this time designed and built to the orders of the navy department. The speed recorded over the three-lap 200 kilometre course was 243.7 m.p.h., but the same machine has since set up the world's record of 266.58 m.p.h. (subject to F.A.I. confirmation) over the measured three-kilometre course. It is to be noted that the new regulation for speed trials to be made over three kilometres instead of the old one kilometre secures far greater accuracy of measurement. The main characteristics of this machine are:—

Total weight	2,097 lbs.
Wing area	148 sq. ft.
H.P.	500
Weight per sq. ft.	14.15 lbs.
Weight per h.p.	4.2 lbs.
Weight of engine (dry) per h.p.... ...	1.36 lbs.

It is obvious that the increase in horse-power of the engine from 400 to 500 is one of the main factors contributing to this astonishing increase in speed, but it is not the only factor. In the 1923 machine the streamlining of the fuselage has been further perfected, the nose in particular being an improvement on the 1922 type.

A new feature is the concealing of the shock absorber inside the covers of the wheel itself. Other differences are:—Reed duralumin propeller, new high-speed wing section, top wing flush with top of fuselage instead of above it with struts.

I ought to mention the Navy Wright Fighters with 700 h.p. Wright engines which took third and fourth places in this race, at speeds of approximately 230 m.p.h., because this speed is well ahead of that of any European machine and it shows that America is not dependent on a single firm for her supremacy.

The Wright is another beautifully designed machine, the general shape and lay out being somewhat similar to those of the Curtiss. With its 700 h.p. it naturally weighs more (2,900 lbs.), but its weight per horse-power (4.1 lbs.) is just better than that of the Curtiss. In streamlining it is not quite so perfect as the Curtiss, *e.g.*, it has Vee undercarriage struts, aileron connecting struts, fuel tank on top plane, gap between top plane and fuselage, ordinary wheels, etc., etc.

The Wright Company is comparatively new to the design of racing machines, but there is every indication from this year's Pulitzer machine that this company will prove to be formidable rivals of the Curtiss Company in the future.

British Post-War Efforts

Although British post-war efforts have not been crowned with success so far as international competitions are concerned, these efforts have been by no means negligible. There is one British firm in particular which has appreciated the significance and importance of high-speed aircraft—the Gloucestershire Aircraft Company—and the highest credit is due to this firm and its able designer, Mr. Folland, for what they have accomplished in spite of the complete lack of support they have received.

As I have mentioned, the Martinsyde Semiquaver with 300 Hispano-Suiza engine put up some fine performances in 1920 and was the British representative in the last Gordon-Bennett Race. After its failure to complete the course through a broken oil pipe the Martinsyde firm, which had achieved so much, was forced to give up aeroplane design through lack of support. But Mr. Folland, who had been largely concerned in the design of the S.E.4 and S.E.5 machines, stepped into the breach and produced the Mars I. or "Bamel" design, in which he employed the 450 h.p. Napier "Lion" engine. The machine represented Great Britain in the Deutsch Cup Races of 1921 and 1922. In the latter year it should have won, for it certainly had a speed higher than the winner's, but was knocked out through a mistake by the pilot. On the next day it flew over the measured kilometre and recorded a speed equal to that of the Nieuport Sesquiplan which then held the world's record at 212 m.p.h.

The latest Gloucestershire racer—the Gloster—won the Aerial Derby in August this year at an average speed of 192 m.p.h. for the 200 miles.

The principal characteristics were:—

Total weight	2,600 lbs.
Wing area	165 sq. ft.
H.P. (approx.)	525
Weight per sq. ft. ...	15.75 lbs.
Weight per h.p.	4.95 lbs.

It will be seen that in comparison with the latest Curtiss Navy Racer the weight per h.p. is considerably higher and the surface loading is also higher. On the other hand, Mr. Folland used a high lift wing section in order to reduce the landing speed.

The fuselage is admirably designed having regard to the engine used, but unfortunately the three-row type of engine does not lend itself to the design of a high-speed machine quite so well as the small angle Vee type. Another point is that gearing of the propeller ceases to be advantageous where such high air speeds are concerned.

The general aerodynamic design of the Gloster would seem to approach that of the Curtiss, but the former must carry more resistance in the undercarriage and probably in the fuselage, due to the less suitable frontage of the engine. But the main difference is in the cooling systems where of course the Curtiss scores heavily.

No other British machine can lay serious claims to being a high-speed machine according to the present day American standard, but reference should be made to the fact that two British radial air-cooled engines of low weight per h.p. have been developed to a high pitch of perfection. These are the 400 h.p. Bristol "Jupiter" and the 350 h.p. Siddeley "Jaguar," whose main features will be found in the Appendix.

The Siddeley "Siskin" with the "Jaguar" engine won this year's King's Cup Race at an average speed of 147 m.p.h., which is a highly creditable performance in view of the high head resistance necessarily involved in an engine of this type.

The Bristol "Jupiter" has recently distinguished itself in a French racing machine in France. A Gordon-Leseurre monoplane fitted with a French-built "Jupiter" engine flew round the Beaumont Cup course (31 miles) at an average speed of 223.7 m.p.h. This curious looking machine has some very interesting features. The chief characteristics are:—

Weight loaded	2,100 lbs.
Wing area	129 sq. ft.
H.P.	450
Weight per sq. ft. ...	16.3 lbs.
Weight per h.p.	4.66 lbs.

The design embodies a new method of dealing with the radial air-cooled engine, each cylinder being separately cowled in in a streamline cover with a slot in front and behind for the passage of air. This arrangement allows of a much smaller diameter fuselage than has been customary in English design for these engines, and no doubt goes far to accounting for the fine speed of this machine. At the same time two other factors must be mentioned; firstly, the undercarriage is made retractable by the pilot during flight; this is done by hinging backwards about the top joints of the front Vee struts and tucking each side of the undercarriage into special slots in the side of the fuselage. The machine is said to be 22 m.p.h. faster with the undercarriage retracted. Secondly, the wing loading and landing speed are very high. However, there is no doubt that this new design opens up the possibilities for this type of engine considerably.

XIIM

High-Speed Seaplanes and Flying Boats

I have so far dealt only with land type aeroplanes, but before concluding with a few general observations I will very briefly refer to the development of high-speed seaplanes and flying boats. Design of marine aircraft has always lagged behind design of aeroplanes, and this is particularly the case in regard to high-speed types. The reason for this is twofold; in the first place there is less incentive to design racing seaplanes or flying boats because the fastest aeroplane must always be faster than the fastest seaplane, and secondly, there is less military demand for high speed in marine types than in land types.

Just as in the case of aeroplanes the great international speed races—the Gordon-Bennett Cup, the Deutsch Cup and the Pulitzer Trophy—have been the incentive to progress in high-speed design and thus in all design, so in the case of marine aircraft the international race for the Schneider Trophy has been the source of inspiration. Established in 1913 this race has steadily increased in significance and it is now universally recognised as the supreme test of progress in the design of high-speed marine aircraft.

The first race was won by the Deperdussin monoplane—a conversion of the 160 Gnome Deperdussin which triumphed in the Gordon-Bennett of the same year, the land undercarriage being replaced by a somewhat elaborate structure carrying twin floats. The speed recorded was only 49 m.p.h., but this does not fairly represent the speed of the machine as part of the course had to be flown over a second time by the winner.

In 1914 the Sopwith "Tabloid"—simply the land machine with floats—won the trophy for Great Britain at a speed of 86 m.p.h. and when the war came this little machine proved to be of the greatest value to the R.N.A.S.

The high-speed seaplane was not developed to any great extent during the war and the line of progress for the flying boat was in the direction of the large long-range machine.

Thus in 1919, when the Schneider Race was revived, the machines which lined up cut rather a poor figure in comparison with the high-speed land machines of the day. This race was abandoned through bad weather, but in the following two years the race was won in Italy by Italian flying boats. In 1920 the winner was a Savoia boat with 450 Ansaldo engine. The speed recorded was only 107 m.p.h., but I believe this was far below the best speed of the machine owing to bad weather conditions. The 1921 winner was a small Macchi with 200 I.F. engine, but this was not by any means the fastest machine entered. Its speed of 111 m.p.h. was far below that of the 700 Fiat Macchi which failed through engine trouble. This big Macchi machine—seaworthy though she no doubt was—shows that the Italians had hardly caught the idea of the marine type racer at this date.

Next year the British Supermarine flying boat with 450 Napier "Lion" engine won the race at 145.7 m.p.h. and thus demonstrated that it was possible to design a small and fast but seaworthy flying boat.

An improved version of this flying boat with a "boosted" Napier "Lion" giving about 550 h.p. was Great Britain's hope in this year's race, and she put up the greatly improved speed of 157.2 m.p.h. But the all-conquering Americans descended upon us with their 1922 Curtiss Navy Racer with 460 Curtiss engine, converted into a float seaplane, and demonstrated that they could beat our best by 20 m.p.h. There are those who say that a light seaplane would not pass the navigability test in rough weather, but there are others—and I confess I am one of them—who thought the sturdy little Curtiss machines eminently seaworthy for racing craft. In any case the Schneider Race is a speed race and I do not think we shall see the trophy back in England till we have sent out a seaplane

whose parasitic resistance—the floats excepted—is as low as that of the best land machine we can design.

As the Curtiss Navy Seaplane Racer holds the world's record for marine aircraft, its main characteristics may be of interest.

Weight fully loaded	2,747	lbs.
Wing area	168	sq. ft.
H.P.	460	
Weight per sq. ft.	16.35	lbs.
Weight per h.p.	5.97	lbs.
Maximum speed	194	m.p.h.
Speed over Schneider course	177.4	m.p.h.

Omissions

I have already extended this paper to too great a length and yet have completely ignored many aspects of high-speed design of fundamental importance. I have, for example, omitted to refer to such questions as the following:—

High-speed wing sections.
Structural strength.
Constructional methods.
Propellers.

To deal with any of these questions at all adequately would prolong the paper to an inordinate length, so I will simply make one comment on each.

Wing Sections

From the earliest days it has been recognised that the most suitable form of section for a high-speed machine is a comparatively thin one giving high efficiency at small angles of incidence. The R.A.F.15 section is a fair representative of the general type of section which is suitable and it will, I think, be found that most of the modern racing machines employ sections of more or less this form, although there is often a tendency to raise the leading edge and thus give the section a more symmetrical form. A large amount of research on wing sections has been done in the last few years, particularly in America, but the most important results have perhaps been in the direction of thick high-lift sections. I was encouraged to leave this aspect of high-speed design alone when I heard so eminent an authority as Professor Bairstow remark in public a few days ago that it does not matter much what section you use within reasonable limits as you always get approximately the same results. He was, of course, referring to ordinary machines in which small differences do not matter, and I am sure he would not hold that view in regard to the modern racing machine. When one considers that in the case of the Curtiss Navy Racer a reduction of .001 in the minimum drag coefficient would mean a saving of 47 engine h.p. at 266.6 m.p.h., it becomes obvious that the choice of wing section for such a machine is a matter of great importance and that there is room for continued research of the most accurate order in this direction. I would add that the greater suitability of the thin wing for high-speed work is one of the chief reasons for the biplane being preferred to the monoplane; it cuts out the cantilever monoplane, and if you have to go to an externally braced monoplane there is not very much saving in resistance over the biplane.

Structural Strength

The design of high-speed machines presents little difficulty from the strength point of view. The racing machine is small and compact and it is easy to cater for the lift forces, which of course are no greater than in an ordinary machine

of similar wing loading. As regards drag forces, the streamlining is carried to such a pitch of perfection and the wings are so small that these forces are quite moderate. I suppose the total resistance of the latest Curtiss Navy Racer amounts to about 500 lbs. at its maximum speed of 266.6 m.p.h.

The main direction in which care is required is in providing a surface covering which is strong enough to withstand the high speed; it will be found that the use of plywood covering for wings, tail units and fuselage has become general for high-speed machines.

Constructional Methods

I am not going to embark on this big question except to say that, partly on account of strength considerations as mentioned above and partly because of the better facilities for streamlining it affords, the plywood monocoque fuselage is now almost standard construction for the high-speed machine.

Propellers

All the modern American racing machines have employed ungeared engines designed to run at revolutions as high as 2,300 or 2,400 per minute at the maximum speed. This introduces difficulty in regard to tip speed, but in the Reed duralumin airscrew, which was used on the Schneider and Pulitzer Trophy machines this year, the Americans appear to have a design in which efficiency is not sacrificed either by small diameter or by unduly high tip speed. British racing machines have so far chiefly employed geared engines and the same difficulty has not therefore arisen. Wooden propellers have been chiefly used by British designers so far, but metal propellers will probably come into general use for future racing types.

It may be of interest to point out that a propeller designed for maximum efficiency at top speed in a racing machine will give very poor efficiency at low speeds. In the case of the Curtiss Navy Racer, with its enormous speed range and its ungeared engine, the power available for getting off must be a small fraction of the full power of the engine, but fortunately this does not matter much as the resistance of the machine is so low that not more than 50 h.p. would be required from the propeller to get the machine off and maintain flight.

Future Prospects

I think the history which I have outlined shows that there have been two great periods in the development of high-speed machines, the pre-war period and the post-war period. So far as I am aware there is not the slightest sign of the post-war development period coming to an end, and I think it is only reasonable to expect that further important progress will continue to be made in the design of high-speed aircraft.

Engine power will increase and engine weight per h.p. will be further reduced, but even with their existing engines American designers will probably achieve considerably higher speeds.

Numerous channels are open to them for further research and experiment. For instance, there is the old question of monoplane versus biplane. At this late stage I cannot embark on a discussion of the relative merits of the two types of construction, but from the achievements of the French it is obvious that the monoplane—in spite of the difficulty of giving it enough area for a reasonable landing speed—has much to commend it, and I confidently anticipate that the Americans will not shut their eyes to its possibilities. Any method of increasing the maximum lift coefficient of a wing without increasing the drag at high speeds

which may be perfected will, I think, tend to bring back the monoplane into favour for racing purposes.

The retractable undercarriage, first introduced on the Dayton Wright machine in the Gordon-Benaett Race of 1920, and lately employed in the Gordon-Leseurre, has considerable possibilities of further development.

And then, apart from the question of material variations in design, there is always the possibility of making further improvements in the streamlining of the fuselage. I do not think the Curtiss machine can be said to have reached perfection in streamline form. It is true the general shape appears to offer little scope for improvement, and the cross-sectional area appears to have been reduced to the smallest size compatible with reasonable dimensions for so powerful an engine, but the actual form of nose of fuselage is not by any means perfect. It may be possible—though perhaps not with existing engines—so to place the engine in the fuselage that the bulges covering the cylinder heads can be dispensed with or at least improved in shape, and thus give the nose a truly streamline form. Such improvements may appear trifling, but even the merest trifle of resistance becomes important at these high speeds.

Anyone who has been concerned with the design of high-speed aircraft will fully appreciate the importance of saving every ounce of resistance, but to those who have not considered the matter it may be of interest that an obstruction causing a resistance of 1oz. at 60 m.p.h. requires more than a horse-power to drag it through the air at 266.58 m.p.h., the present record speed. With h.p. required to overcome parasitic resistance going up as the cube of the speed, it will obviously become more and more difficult to beat the record, but I do not see any indication that we are yet approaching the limit of speed. I suppose that the Curtiss Racer could now, with smaller wings and further slight refinements, reach 300 m.p.h., while I am confident that the speed of the Navy Wright Racer will be greatly increased. It seems to be highly probable that a speed of 350 m.p.h. will be achieved within the next two or three years.

I have plotted a curve showing the increase in the speed record from year to year since the war and it will be seen that it shows no indication of the limit having been approached.

Value of Speed Races

I have endeavoured to show how great has been the effect of the various international speed races in the evolution of the modern high-speed machine, and I think it will be agreed that but for the stimulus of these races America would not have advanced anything like so far as she has in the design of this type of craft. America wanted to lead in this direction and she realised that the encouragement of racing was the best means to achieve that end. She therefore gave the most rational form of encouragement she could; the most competent firms were given orders for experimental racing machines, and although given a free hand to produce the best they could they were thus relieved of financial risk. The result of this policy is that America has become the leading air Power for an insignificant expenditure. For in solving the difficulties of high-speed flight she has acquired information and experience which place her technically ahead of all other nations, and it is the technical leaders of to-day who will be the military leaders when the military occasion arises.

I would summarise the advantages of encouraging the design of racing aircraft as follows:—

(i.) It develops highly efficient and reliable engines.

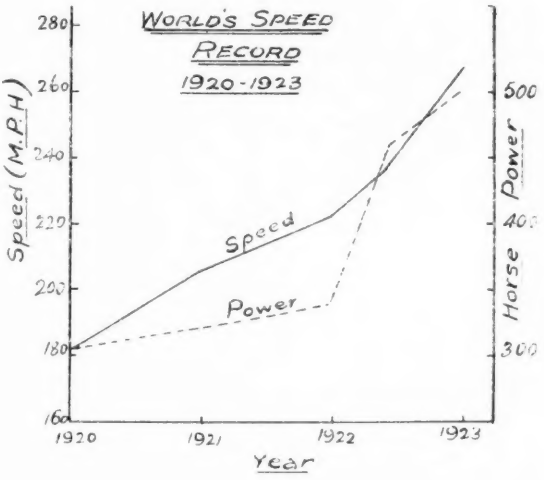
(ii.) With slight modifications the racing design can be converted into a single-seater fighter design of the highest possible efficiency.

(iii.) It keeps the minds of designers awake to the necessity of good streamline form and reduction of head resistance.

(iv.) The results obtained are applicable in some degree to every military type.

(v.) It keeps highly skilled designing staffs in practice and in touch with the latest developments and research.

(vi.) The results obtained are applicable in the design of commercial types of aircraft.



I would go further than this and say that the future hope for air transport lies in the design of more efficient commercial aeroplanes. I must not, however, at this late stage embark upon a discussion of commercial aeroplanes, but will simply remark that if the cruising speed of the commercial machines in service could be raised by 20 m.p.h. without reducing load or increasing power required it would revolutionise the financial aspect of commercial flying. I believe that it would be quite possible by applying the lessons learnt from the latest Curtiss Navy Racer to achieve a good part of this extra speed in a new design of commercial machine, without seriously impairing its commercial qualities.

The D.H.34 is the fastest large commercial machine, which has done such admirable service on the continental routes, and little imagination is needed to decide how some of the extra 20 m.p.h. required could be gained. The D.H.50 is a later but much smaller type, and it will be seen that this machine appears to show improved qualities in regard to streamlining.

(vii.) The winning of international races has a most important moral effect and adds enormously to the prestige of the winning nation.

Conclusion

In conclusion I would repeat that the splendid achievements of American designers in the development of high-speed aircraft have been due entirely to the fact that the American Government has properly appreciated the significance of research and experiment, and has allocated the available funds accordingly. I do not think I could express this more clearly than by quoting some words spoken by Commander Hunsaker, U.S.N., Chief of the Design Division of the U.S. Naval

Bureau of Aeronautics, after this year's Pulitzer Race, which, by the way, was witnessed by over 100,000 enthusiastic Americans.

"This is no Roman holiday. It is the focus of applied science. We set out to develop certain types of planes and engines for the service needs of naval aviation. Nothing that makes for safe and reliable operation of these planes and engines was neglected. The planes were thoroughly tested in the wind tunnel, then for engine performance, then statically, then in flight. When we came here we had every assurance that we had planes as fast as it is possible to build to-day. We have now proved to the world that American scientists and engineers can build, and American pilots can fly, the fastest planes in the world, which also means that we possess the best aircraft engines. We looked for quality instead of quantity, and we got it.

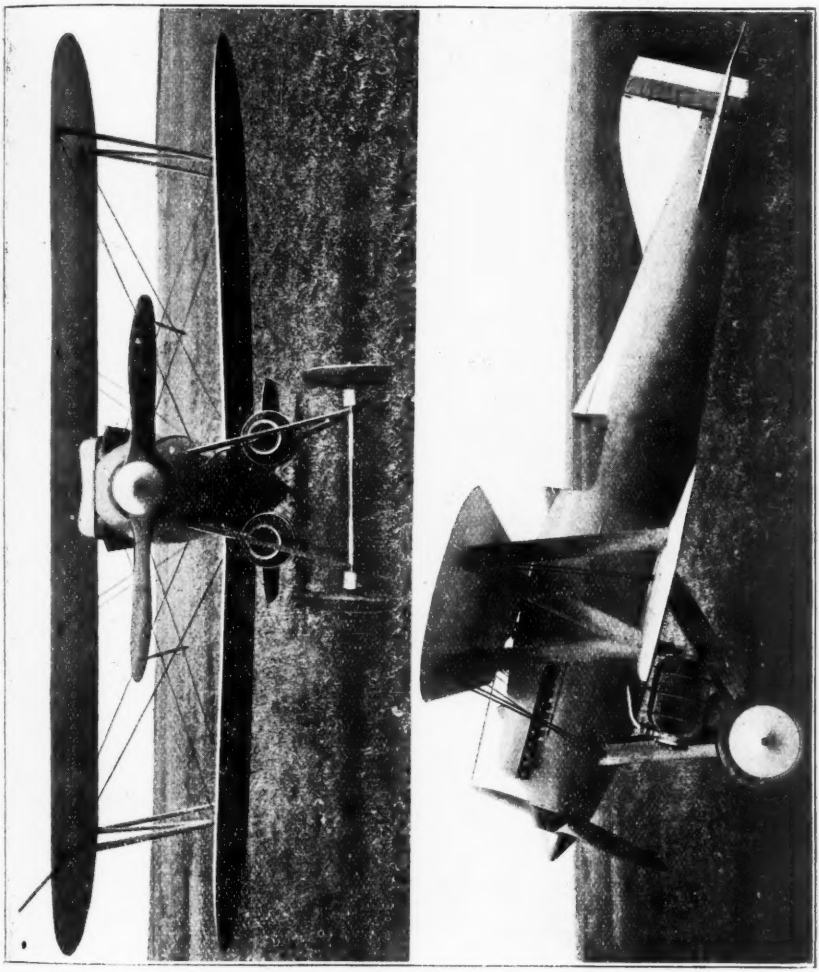
"The Curtiss and Wright engines used in the Pulitzer Race are not racing freaks, but regular service types. The Navy Department has placed orders for 100 engines each for the two types of engines, the Curtiss for our smaller planes and the Wright for our bombing and torpedo planes. The race has vindicated our policy of developing service types of engines through high-speed trials where the utmost is asked of a power plant. While the racers are not strictly speaking fighting machines, their new and now tried features are readily available for use in service types."

I submit that British air policy has been fundamentally wrong since the end of the war. British air votes have not compared unfavourably with those of other nations, but where has the money gone? In every possible direction except the one that matters. Research and experimental development are practically at a standstill in Great Britain because there is no money to pay for them, and yet the latest air estimates were for over £12,000,000. What is the use of expanding the Air Force if we allow ourselves to sink into such a position that when war comes we shall be technically out-classed by other nations?

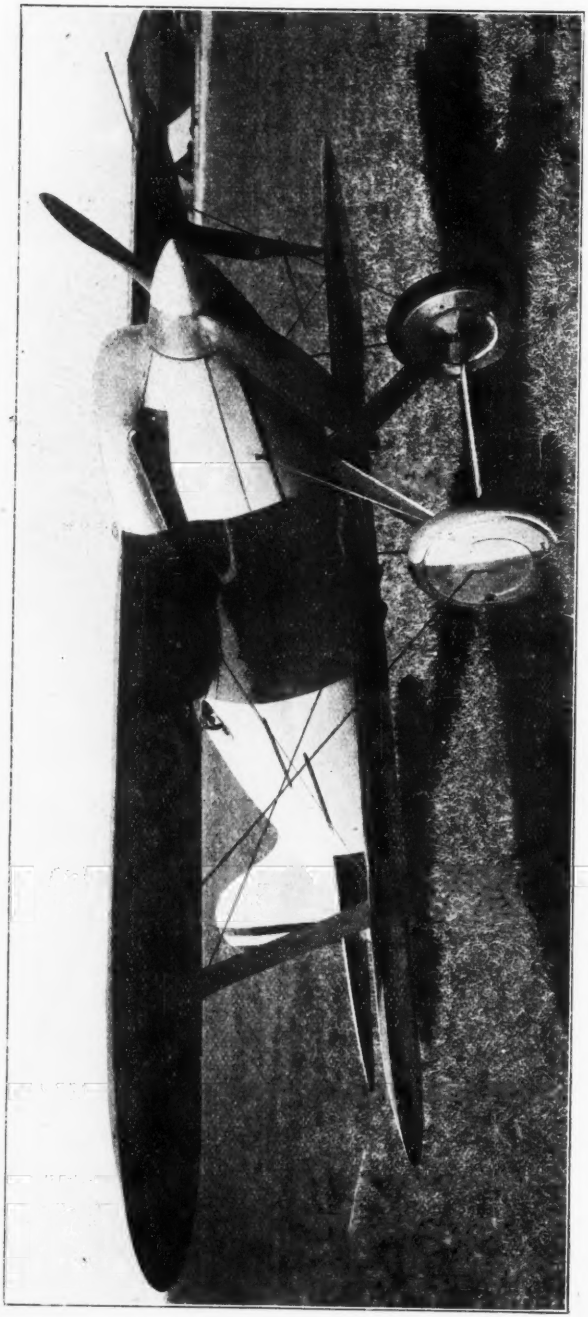
By her vigorous technical policy America has placed herself well ahead of any other nation in the design of high-speed aeroplanes and the development of suitable engines, and her position as the leading air power is secure for some time to come. Fortunately for us America and Great Britain will never fight against each other.

But if it is worth while spending 12 millions a year on an Air Force, surely it is worth while making provision for the best possible technical equipment of that Air Force? British research workers and designers are capable of producing results as good as the best, but they must be properly backed by the Government. The American method of encouraging development is eminently sound in principle and successful in result. Would it not be worth the Government's while to follow their example and allocate, say, half a million pounds a year for the express purpose of encouraging British efforts to win the Pulitzer Race and bring back the Schneider Trophy? Whether these happy results were attained or not, the experience and knowledge gained would be cheap at the price. I do not think there would be any difficulty in finding the money if the general public knew the facts.

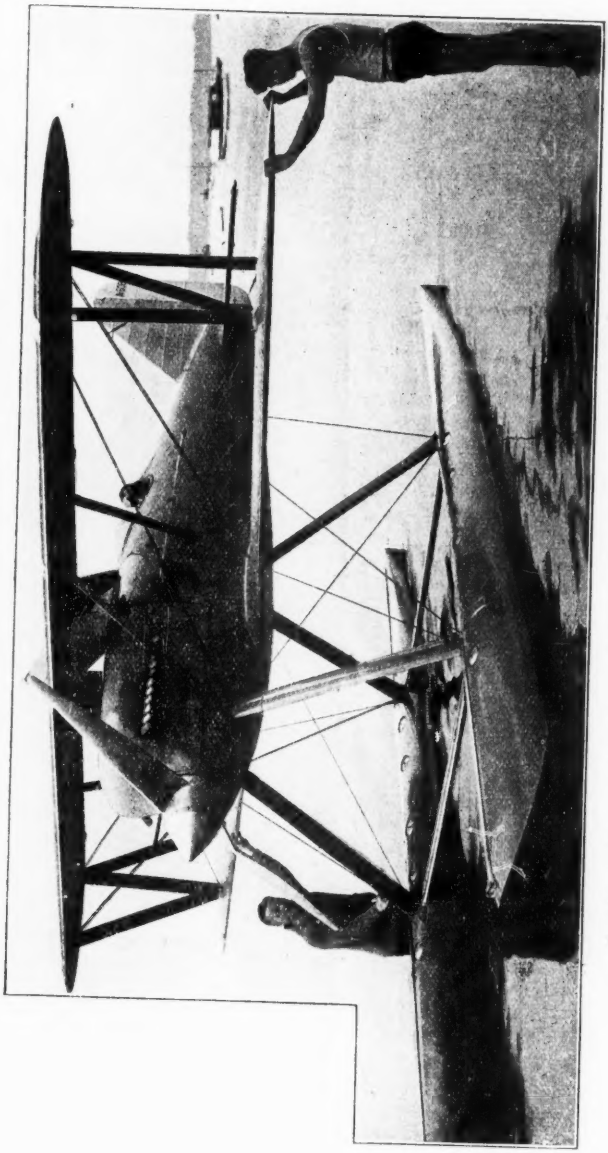
I have to thank the Air Ministry, the "Aeroplane," "Aviation," Messrs. de Havilland, Colonel Ogilvie and the Society for very kindly supplying slides, photographs or technical data.



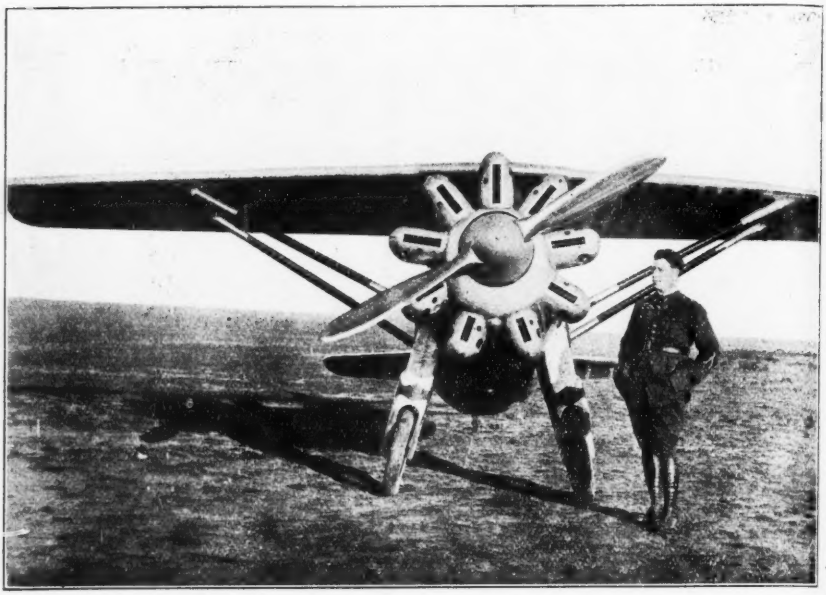
Curtiss "Navy" Racer (405 h.p. Curtiss C.D.-12).



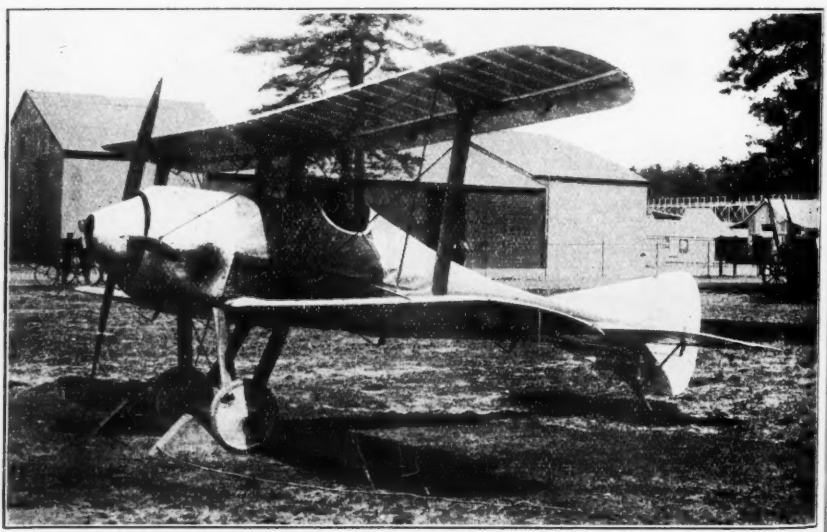
Curtiss "Navy" Racer (1923) with 500 h.p. Curtiss Engine.



Curtiss "Navy" Seaplane Racer (1923) with 460 h.p. Curtiss Engine.



Gordon-Lescurre Monoplane with 400 h.p. Bristol "Jupiter" Engine.



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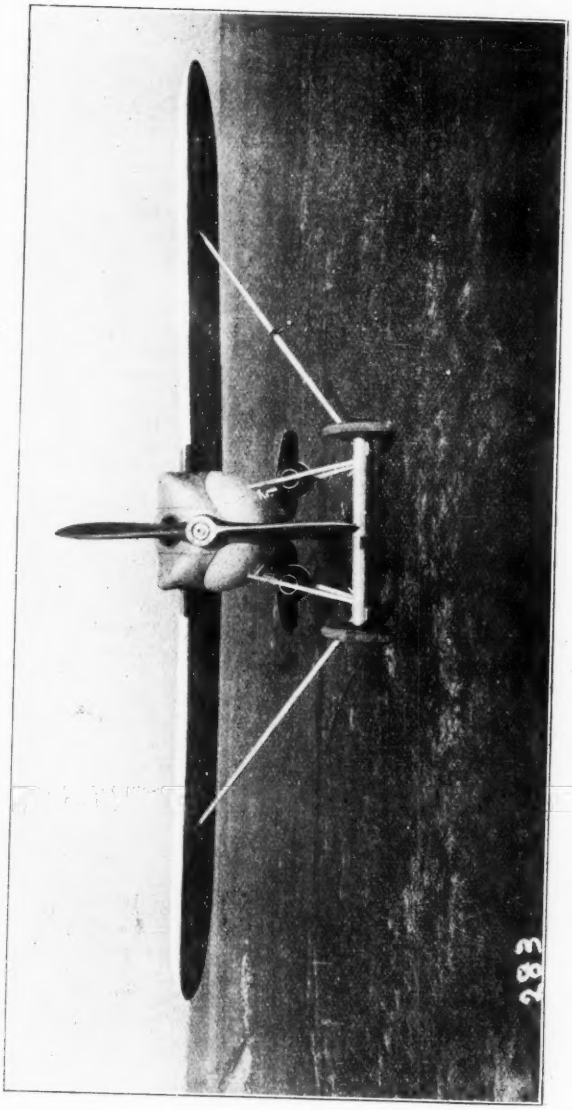
NOTE.—*The original tripod undercarriage has been replaced by one of V type.*



Nieuport "Sesquiplane" with 300 h.p. Hispano-Suiza Engine.

APPENDIX

PARTICULARS OF PRINCIPAL ENGINES REFERRED TO IN PAPER

I. AIR-COOLED ENGINES.

Name.	Nominal H.P.	Type.	No. of Cylinders.	Weight (lbs.).	Maximum Effective B.H.P.	Weight in lbs. per Effective B.H.P.
Gnome	50	Rotary	7	172	45	3.8
,, ...	70	,,	7	192	55	3.5
,, ...	80	,,	7	207	72	2.9
,, ...	100	,,	14	308	90	3.4
,, ...	140	,,	14	297	110	2.7
,, ...	160	,,	14	396	145	2.7
Le Rhone	80	,,	9	268	90	2.98
,, ...	110	,,	9	336	131	2.56
Clerget	130	,,	9	385	134	2.87
B.R.2	230	,,	9	498	230	2.165
Armstrong Siddeley Jaguar	350	Radial	14	760	390	1.95
Bristol Jupiter	400	,,	9	740	425	1.74

II. WATER-COOLED ENGINES.

Name.	Nominal H.P.	Type.	No. of Cylinders.	Dry Weight (lbs.).	Maximum Effective B.H.P.	Dry Weight in lbs. per Effective B.H.P.
Curtiss	30	Vertical	4	162	30	5.4
Hispano Suiza	150	Vee (90°)	8	440	165	2.66
,, ,, ...	200	,,	8	515	220	2.34
,, ,, ...	300	,,	8	595	308	1.93
,, ,, ...	300	,,	8	595	340	1.75
Rolls-Royce Eagle VIII.	360	Vee (60°)	12	926	375	2.47
Napier "Lion" ...	450	3-row (60° and 60°)	12	900	450	2.0
,, ,, ...	450	,,	12	900	525	1.71
Curtiss	400	Vee (60°)	12	642	400	1.65
,, ...	500	,,	12	687	503	1.36
Packard	600	,,	12	1100	600	1.85
Wright	700	,,	12	1150	700	1.65

Discussion

The Chairman said that we could not help paying attention to the vigorous words of Major Mayo, particularly in the last part of the paper, and he very much regretted to see that a very small number of representatives of the Air Ministry were present. It was a useless policy to put one's head under one's wing and maintain that one could not see anything.

Professor L. Bairstow said that Major Mayo had given an extremely interesting account of the development of high-speed aircraft, and it was particularly interesting, not only as showing the technical development—the way in which the high speeds of 250 miles per hour and upwards had been reached—but more particularly as showing the effect of the psychological factor. The aeroplane began its modern phase in America, but official and public America was not particularly interested in aircraft, and as a consequence early development occurred elsewhere. The policy of our own Government was, to say the least, lukewarm. The enthusiasts of the period were the French, who went ahead and left everybody else behind. Then, somewhere in the neighbourhood of 1909 and 1910, the policy of Great Britain changed. Great Britain decided then to go in for aeronautical research. Perhaps it did not go so far as many people would have liked, and it did not encourage design sufficiently; but, at any rate, a certain amount of enthusiasm was created in this country and we went ahead. At the present time the enthusiasm is in America, and America is going ahead. He did not think it was so much a difference of temperament between the populations of the various countries as a difference of policy, and he believed that Britain owed its present poor position in the race for high-speed aircraft entirely to Government policy. There were two ways in which policy affected progress. In the first place, if there were no money we could do nothing at all, either in design, research, or anything else. Of course, research costs money, but as compared with the production of a particular design of aeroplane, to test each point raised research was relatively inexpensive; as a preliminary, therefore, a certain amount of money was necessary. The second manner in which policy affected progress—and in many ways the most serious one—was the placing of the control of research in unsuitable hands. This mattered much more than most people seemed prepared to believe. It was not sufficient that a man should be sympathetic; he must have knowledge if progress was to be directed properly. The lecturer had not said very much as to what the American organisation was, but he had said that the Americans had an organisation for research which was unparalleled in any other country in the world. In particular they had, at Langley Field, a full-scale research laboratory organisation which we in Britain had never had. Not in our best times had we had a full-scale laboratory under the charge of scientific advisers. That, he believed, was the outstanding feature of our present position, and one might perhaps be forgiven for hoping that the common-sense of the British nation would presently get us out of that position. Looking at the technical results that America had obtained, one could see just how research had affected their position. He had taken part in the discussion in this country as to the value of wing radiators, but those radiators had not been applied to British aircraft because we had no data which would enable the designer to say just what would be the effect of wing radiators, and until we had there would be reluctance to make the wings perform double functions. America had found out how to do it, and the big loss of power which came from keeping the engine cool was largely avoided by using the drag of the wings, which we must necessarily have in any event. We had known for some years that skin friction was a most economical method of cooling, but hitherto we had applied our knowledge of that fact by the use of the honeycomb radiator. We had known that the cooling of cylinders

as in the rotary engine was expensive relatively, but, after looking at the photographs which the lecturer had shown, he could see no point which we as a nation could not have reached had we been given the same facilities as had been given to Americans.

There was another point he wished to mention. The lecturer had repeatedly quoted the loading per horse-power of these aircraft, and the loading per sq. ft. They were very useful figures, but, of course, one realised the performance of an aeroplane was made up essentially of three different factors. The first, and the part which had been most important in British progress, had been the development of powerful engines; the second part was the development of a light structure, and the third was aerodynamic efficiency. It was possible, if one were given full facilities and time—which he was pretty certain the lecturer could not have had—to separate out these three, one could get the weight of the structure, measure the horse-power, and deduce from the tests what the aerodynamic efficiency was. Our war experience showed that, whilst we went forward with regard to horse-power, we went backwards with regard to aerodynamic efficiency, and America was securing a great part of her present success by taking up the problem of aerodynamic efficiency. With regard to the control of these craft, it appeared that the piloting at high speeds needed unusual skill, and if they are produced, then Britain will need pilots who could handle them. Perhaps an illustration of the delicacy of this control, even if very incomplete, will show how extremely difficult the control of the high-speed aeroplane was as compared with that of the low-speed aeroplane. Supposing an aeroplane was flying at 250 m.p.h. horizontally; we knew, from our experiments, that the angle of incidence, measured from the angle of no lift, was somewhere between half a degree and one degree, so that, if the pilot moved his elevator sufficiently to turn his aeroplane by less than a degree in one direction, he doubled his load; but if he turned it in the other direction, he removed his load entirely. The evidence of pilots was that at these very high speeds—something much less than 250 m.p.h.; say, anything between 100 and 200 m.p.h.—there were occasions on which, unless strapped securely into their seats, they were apt to be bumped from them, and it was quite easy to make a calculation to show how much down current would be necessary in order to make a pilot leave his seat. The calculation was a little complicated by the fact that nearly all racing machines were very heavily loaded; but, leaving that out of account, a pilot flying into a down current of about 3ft. per second when travelling at 250 m.p.h. would leave his seat. At 100 m.p.h. the down current had to be about 8ft. per second, whilst at 50 m.p.h.—a speed we should think of in connection with light aeroplanes, such as those which had recently competed at Lympne—the down current required to remove lift temporarily would be about 15ft. per second. Those figures compared with actually-recorded down currents—recorded by the Meteorological Office—of 8 or 9ft. per second, and it would be seen that the frequency with which a pilot would be disturbed from his seat went up as the speed of the machine went up, so that the whole method of managing these high-speed aeroplanes was a matter which needed attention. The research which is here indicated would also throw light on the associated structural problems. If the pilot should make a slip in using his elevators, or come to a particularly bad down or up current, his loading might be increased five or six times, and the factor of safety of the machine for ordinary flying would then be no greater than that of the ordinary fighting aircraft during the worst of manœuvres.

In conclusion, he congratulated the lecturer on having brought forward so much valuable information at such a time in the history of the development of high-speed aviation.

Mr. LAWRENCE SPERRY, referring to the production of these racing machines in America, said that, for the 1922 race, all the orders were given to the various constructors about $3\frac{1}{2}$ months before the race, which showed how quickly it was

possible to produce racing machines, whereas, with the regular military types, it had taken sometimes as long as three years to get a new type out, because of the necessity for exchanging drawings with the Government technical people. The elevators of some of the recent racers were fitted with a cam, whereby greatly reduced gear was effected when working round the neutral position of the elevators, without reducing the total motion thereof.

Colonel O'GORMAN said he had listened with keen interest to Major Mayo's paper. It was not very often that a technical man, having the ability, the will and time to give them an instructive paper, chose the historical method of inculcating the lesson he had to impart. He had selected one particular aspect of aeroplane performance—speed—and by a reasoned history not only brought home the technical lesson, but stirred the desire to avoid past errors for future projects. We could wish for more papers on these lines, and if Professor Bairstow could himself spare the time, no one could do better than he, precisely what he wished Major Mayo to do.

Looking round the room and using the eye of the imagination, Colonel O'Gorman congratulated the Society on the presence at the meeting of those persons in office in the Ministry who could most easily and profitably act upon the lesson given. Imitating his distinguished predecessor, General Henderson, he saw sheltering behind the halo of his titles and style—but still amply present—the form of Sir Hugh Trenchard. Similarly, now that the British position in the world of aeronautical technical achievement was somewhere about the lowest of the Great Powers, he saw the Air Minister, Sir Samuel Hoare, M.P., following in the footsteps of General Seely, who used so frequently to attend their meetings when the British held the premier position in technics. He, too, would in that way illumine some corner of his technical darkness. There also was the Air Vice-Marshal, who was Member of the Air Council, called the Member for Research and Supply, in the very charming personality of Sir Geoffrey Salmond—attended by his head man, General Bagnall Wild, Director of Research. Seeing that all these really interested, both by their official business and their careers, and the supremacy of their arm and the safety of their country, were present, naturally large numbers of the more live members of the Air Bureaucracy were there, learning in this unofficial atmosphere what it was that the keenly-interested aeronautical public desired for the progress of their science, and what it was that the aeronautical engineers and scientists of the country considered useful, or advantageous, or cardinal for advancement.

Unfortunately this was but a phantasy. As our lecturer had intimated, all the " world records " for speed and performance had settled firmly into the grip of those nations whose technical control was not in the hands of the British Air Ministry; and as for the Air Ministry Staff, why should they attend when they were under no illusions as to scientific knowledge assisting to forward their careers?

It would seem that persons in high aerial places who had the right to deck their heads with comic headgear on gala occasions had unfortunately met a few scientific cranks (for these *do* exist in all walks of life and often show a tendency to gravitate round ill-informed persons in high authority). Presumably from this contact with what posed as science the idea seems to have taken root among the powerful in air matters that technical aptitude was incomparable with what posed as science the idea seems to have taken root among the powerful in administrative ability, *e.g.*, it was to his knowledge stipulated in 1917 that the head of that highly-scientific laboratory the Royal Aircraft Establishment should *not* have aeronautical technical knowledge!

In so fundamentally scientific and technical a service as the air, no such erroneous creed should be capable of acceptance, but so long as it is accepted there is no career for the skilled scientists and therefore no queue of good and capable tech-

nical persons for the posts they and they alone should fill. This was not a recent disease. For long there had been lacking that psychological atmosphere to which a previous speaker had alluded—which made for progress, for courage in taking the risks of experiment at long range, for perseverance under the delays, set-backs and surprises of research work. He would give an example to show that whatever sympathy may be felt for, or whatever thunderous demands made for, a technical achievement, when the scientific appreciation was *nil*, the result is miserable, and consequently we were very severely handicapped during the war. He took for example *speed*.

There could be no question in view of the great publicity given to the matter, and of the actual painful knowledge of our fliers, that speed was reckoned to be badly wanted in the early, middle and late parts of the war. At that time, then, our good cause was sympathised with. In the early and middle parts of the war he was personally and profoundly concerned with helping forward the attempts to acquire speed, but, in spite of the pressure put by himself, as the Chief Technical Officer to the Government at that time, to secure speed, everything that could be imagined which would impede speed was immediately, and as it has since been proved and was then stated *uselessly*, applied to aircraft on which provisions for speed had been made. The sympathy existed, but the knowledge did not. The speed required by using fair lines, fair struts, fair wires, and a smooth well-studied exterior was abolished by making a Christmas tree of the aeroplane. They would remember how one and the same aeroplane was fitted with as many as seven projecting gun mounts, rows of bomb carriers in supports, external camera supports, external bomb-sights, and practically any gadget that the ill-informed ingenuity of the aerodynamically ignorant could desire. He had pleaded metaphorically on bended knee against these gadgets. They would remember that increased engine power, which was the *only* alternative to fine lines for attaining speed, was prevented by the authoritative prohibition of the men in charge, and that when they woke up to this error it took eighteen months to get such increased engines into production. Having cut off all avenues to speed, the Air Board continued to howl for it. There are countless examples of the same kind.

At present and for the last four years we have been gravely short of money for experimental research, yet ignorance of what experimental research is has led to the wasteful expenditure during that period of shortage of over £70,000 on an *ad hoc* experiment of the most fatuous kind on a helicopter. This sum is about three times the annual expenditure at the National Physical Laboratory in aerodynamical research. Would this have happened if we had a scientist on the Air Council? He begged leave to doubt it.

Previous to the war there was an instance which has not hitherto been recorded in any history. He had indicated to the then Secretary of State for War that it would be a great advantage to the country if it were to be in possession of the fastest aeroplane in the world in the form of a design available for construction and tried out in practice. Colonel Seely, the Secretary of State, agreed and ordered the machine at a cost of £3,000. It was made, and when tried flew at 131 miles per hour (at a date when the fastest known aeroplane abroad had the world's record at 112 and 115 m.p.h.). So far so good. But no sooner was this done than the military head of the Air Force, then called the Flying Corps, handed in his resignation in person *because such an order had been given*, and a new order to discontinue this work was received by the makers of the machine in question.

Until the war came the appreciation of the value of speed, of the possibility of combining it with reasonable safety in alighting and safety in the air, was not really grasped by any but the scientific and technical advisers of the "Air Council" of that day. Indeed, military and other flyers of to-day would be surprised to realise that for years before the war had stung the Brititsh aeronautical

world into the appreciation of the supreme utility of speed it was looked upon mainly as a form of advertisement, to which French constructors were addicted for sensational reasons.

One would have supposed that a military quality like speed would receive the best recognition from such an air authority, or council, as we had then and have now, and certainly the quest for speed would not *a priori* have promised to be a subject on which it would be possible to show that the presence of a science member on the Air Council would be more helpful than the military members, or than the C.A.S. himself. Yet so it was and so it would infallibly be found to be as regards every technical development.

When the biggest aero engine in the country was 120 h.p., who pressed for construction of a 200 h.p. engine?—the Scientific Adviser! Who successfully opposed, nay, forbade the construction?—the "Air Authority" of that date, as he confessed before the Bailhache Commission!

When pilots frequently lost their way in the clouds, and consequently like Hamel and others were drowned because their compasses gave them false readings, who solved and cured that difficulty and made a compass whose indication avoided the turning error? It matters not here who did it; what matters is that the air authority of the day, being actually provided with the correct compasses, authorised and ordered them to be changed back to their old erroneous quality—for lack of a science member who could understand what the trouble was due to and how the cure had in fact been effected.

In fine, Colonel O'Gorman claimed to contribute to the discussion of Major Mayo's paper a solution; indeed, the only possible solution for the state of trouble and depression in which British aero technics found themseves. They must have, and must insist on having, a representative of science on the Air Council, whose duty shall *inter alia* be to study at the inception of any air policy the effect of the existing technical position of the world on such policy and the effect of such policy upon the technical position of England in the world of aeronautics. Moreover, he should see to it that there is no handicap against a flying officer who is well versed in science, but on the contrary that there shall be a career for him in a technical or scientific branch of the Air Service, wherein, other things being equal, he can rise to a standing and emolument as comforting as those which fall to officers who do not "waste their time on technics."

The CHAIRMAN emphasised what Colonel O'Gorman had said—that it was impossible to talk to high officials who had no technical knowledge. One simply could not make them understand what one meant. If Colonel O'Gorman, with his extraordinarily easy flow of language, could not succeed, then no one else stood a chance. His own experience confirmed that of Colonel O'Gorman. It was only when we had a man at the top who had an understanding of engineering matters that we really made the progress we should.

Major MAYO, in reply, said he was extremely interested in the remarks which had been made by the speakers. He agreed entirely with Professor Bairstow that it was an extraordinary thing that we should not have a full-scale laboratory here, as in America, and if the Government would wake up to the present position, that ought to be one of the first things to be put right. With regard to Professor Bairstow's remarks as to the analysis of weights of the American racing machines, that, as he had rightly surmised, had not been gone into, mainly because the time had been so short. If he (Major Mayo) had had time to go into it, he had no doubt the information would have been forthcoming. He had noticed that the Americans, who are doing most of the new work in aeronautics at the present time, are publishing their results, and, as a matter of fact, he had found much less difficulty in collecting data in regard to the latest American racing machines than he had in regard to any others. It was all published in excellent form in the American technical press. He had no doubt that an inquiry into the struc-

tural weights of these machines would prove very interesting. Some light would be thrown on the question by comparing the total weights of the various machines with the weights of their respective engines given in the Appendix to the paper.

He had not attempted to go into the question of the control of racing machines, because it would have made the paper too long. As to a pilot coming out of his seat as the result of a slight down current, he had read an account of the 1923 race from the pilot's point of view, and had noticed that the pilots had strapped themselves in very carefully with special straps—the same type as was used for stunting, looping, and so on. Therefore it looked very much as though those pilots had experienced the sensation referred to. He did not think there was any very great difficulty in controlling these machines under normal circumstances. They could be made to slip round a corner in a most astonishing way. Sadi Lecointe used to do that in the international races, and he believed it was something less than three seconds, or some extraordinary figure like that, from the time he was flying in one direction on the course to the time he was passing again in the opposite direction. He (Major Mayo) had also seen photographs of American pilots going round the pylons without difficulty.

It was interesting to hear Mr. Sperry state that the racing machines took such a short time to design and construct. One would not have thought so, judging from the fine degree of perfection with which the work was done; but, that being so, there was all the more reason why that was a good line of development, and a thing which the Government might reasonably support. If it would take two or three years to design, construct, and thoroughly test a new type of military machine, it was obvious that we could not be getting out new military types all the time; they would cost too much money. But if we kept on developing these racing machines we should keep abreast of the times in regard to research, and then, when the occasion arose for the introduction of a new military type, we should be sure of getting an up-to-date one.

He had been very interested indeed to hear Colonel O'Gorman's reminiscences of the remarkable period he had mentioned, and he could confirm entirely what had been said with regard to the particular machine referred to. In the paper itself he had made reference to the fact that that machine, the S.E.4, was never taken up, and there was no adequate reason for that. The impression got about that it was a dangerous machine because it landed at so high a speed. That, however, was pure nonsense. As a matter of fact, it landed at 48 m.p.h., which was a very much lower landing speed than that of many other types of the period. The trouble was that the authorities could not adapt their minds to a machine which was so great an advance on previous machines. There was no technical reason why we should not have had, soon after the beginning of the war, machines which would have done, with military equipment, not quite as well as the S.E.4, but pretty nearly. The maximum speed of our fighting machines during the first two years of the war was about 90 m.p.h., and, as he had remarked in the paper, when the D.H.4 two-seater came along in the autumn of 1916, the speed of that machine was about 120 m.p.h. at ground level, which was a considerable advance on that of any previous service machine.

A hearty vote of thanks was accorded Major Mayo at the close of the meeting.

R.38 MEMORIAL PRIZE, 1923

The Council have decided, for this year only, to increase the amount of the prize from 25 guineas to 40 guineas and to divide this sum between the papers on "The Aerodynamical Characteristics of the Airship as Deduced from Experiments on Models, with Application to Motion in a Horizontal Plane," by Mr. R. Jones, M.A., and "A Detailed Consideration of the Effect of Meteorological Conditions on Airships," by Lieut.-Col. V. C. Richmond, O.B.E., A.F.R.Ae.S., and Major G. H. Scott, C.B.E., A.F.C. They also desire specially to commend the paper on "The Strength of Rigid Airships," by Mr. C. P. Burgess, Commander J. C. Hunsaker, U.S.N., Hon.F.R.Ae.S., and Mr. Starr Truscott. All three papers will be published in the Journal.

A DETAILED CONSIDERATION OF THE EFFECT OF METEOROLOGICAL CONDITIONS ON AIRSHIPS

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In presenting this paper the authors are conscious of the fact that it contains very little information which is actually new. They feel, however, that the collection and co-relation of items of theory and experience which may not be widely known will prove useful to those who may have to consider the employment of airships on long journeys through necessarily varying meteorological conditions.

The meteorological factors of principal interest are temperature, pressure, density, wind, humidity, rain, snow and electrical disturbances. It is convenient to consider the effects of these under three main headings, viz. :—

(1) Effect on the navigation of airships.
(2) Effect on the choice of sites for aerodromes.
(3) Physical and chemical effects on the airship's structure.

1 *Effects of Meteorological Conditions on the Navigation of Airships.*

These effects may conveniently be sub-divided under the following headings, viz. :—

(*a*) Effect on the lift of the airship.
(*b*) Effect on the dynamical behaviour of the airship.
(*c*) Effect of wind, etc., on the course made good.

1*a* *Lift*

For all practical purposes the pressure of the gas contained in an airship may be considered equal to that of the external atmosphere. The gross lift of the airship may then be expressed in one of the following general forms :—

Let T_a = the absolute temperature of the air and T_g = absolute temperature of the gas.

$$\text{(i.) Gross lift} = \frac{\text{total capacity (cu. ft.)}}{1000}\left\{.9305 \times \text{purity of gas} + \frac{T_g - T_a}{T_a}\right\} \times 78.2 \times \text{percentage full at sea level (lbs.).}$$

The lift of the airship is independent of the barometric pressure, and if it were possible to keep the gas and air temperatures always equal to one another, it will be seen that the lift would also be independent of temperature, and hence of altitude up to the "pressure height" of the airship. This formula takes no account of humidity, which will be considered separately later.

The term—" percentage full at sea level "—is meant to apply to conditions of Standard Atmosphere* under which the sea level barometric pressure = 1,014 millibars and the sea level temperature = 282°C. absolute, and it is on these figures that the numerical constants in the equation have been based. Percentage fulness at sea level is rather a difficult and uncertain term to work with and may conveniently be replaced by the relative density of the gas at " pressure-height." Thus, suppose the airship is taken up until the automatic valves just begin to blow off and at that instant the barometric pressure is P_h millibars and the gas temperature T_h °C. absolute. Then the expression for gross lift becomes:

$$\text{(ii.) Gross lift} = \frac{\text{total capacity (cu. ft.)}}{1000}\left\{.9305 \times \text{purity of gas} + \frac{T_g - T_a}{T_a}\right\} \times 78.2 \times \frac{P_h}{T_h} \times \frac{282}{1014}$$

Effect of Change in Temperature and Pressure at Sea Level

Neglecting superheat equation (i.) may be written

$$\text{(iii.) Gross lift} = \frac{\text{total capacity (cu. ft.)}}{1000} \times .9305 \times \text{purity} \times 78.2 \times \text{percentage fulness at sea level.}$$

Suppose that instead of standard atmospheric sea level some other zero altitude is being considered, where the barometric pressure is P_z millibars and the temperature is T_z °C. absolute. Then the above equation may be written:—

$$\text{(iv.) Gross lift} = \frac{\text{total capacity (cu. ft.)}}{1000}.9305 \times \text{purity} \times 78.2 \times \frac{P_z}{T_z} \times \frac{282}{1014} \times \text{percentage fulness at zero altitude.}$$

If it is intended to work between *the same limits of altitude in all parts of the world* it is obvious that the factor $(P_z/T_z \times 282/1014)$ gives a measure of the effect of varying climatic conditions on the lift of the airship, if P_z and T_z are normal average sea level pressure and temperature respectively and superheating and humidity are neglected for the moment. To illustrate this point, certain important points on the route from England to Australia have been selected and the mean values of the normal sea level pressure and temperature, month by month, have been shown in Tables 1 and 2. The corresponding values of the factor $(P_z/T_z \times 282/1014)$ have been shown in Table 3. It is thought that Table 3 may prove useful in scheduling the performance of commercial airships flying on such a route. It indicates that, on the average, the lift of an airship in regions such as Bombay and Colombo will only be 94 per cent. of the corresponding lift in England and for extreme cases this figure will be reduced to 91 per cent. The table indicates sufficiently clearly the effect of mean seasonal variation in meteorological conditions at the places mentioned.

Another way of dealing with the same point is to trace the effect on the ceiling of the airship if the lift is supposed to remain constant.

Let the percentage fulness given in equation (iii.) $= x_1$.
" " " " (iv.) $= x_2$.

If the gross lift is to remain the same in the two cases, it will be clear that x_1 must equal $(P_z/T_z \times 282/1014)\, x_2$.

$\therefore x_2/x_1 = T_z/P_z \times 1014/282 = 1.067$ for an average case or 1.1 for a maximum case between London and Bombay, as shown above. Now the percentage fulness is equivalent to the relative density of the air at " pressure height," and to trace the average effect on the ceiling of this change in percentage fulness it is necessary to know the relationship between relative density and height. Unfortunately, data showing the variation of meteorological conditions with height in

* *Vide* Reports and Memoranda of the Aeronautical Research Committee, No. 509.

TABLE 1.

SHOWING MEAN SEA LEVEL PRESSURES IN MILLIBARS (P_z).

	Jan.	Feb.	March.	April.	May.	June.	July.	Aug.	Sept.	Oct.	Nov.	Dec.	Average.
Greenwich ...	015.5	015.9	014.0	013.4	015.4	016.1	015.5	015.0	016.0	013.1	014.4	015.2	015.1
Marseilles ...	017.0	016.4	012.8	012.7	013.4	015.0	015.1	015.1	016.2	014.8	014.8	016.3	015.0
Rome	017.1	016.5	013.2	013.9	014.3	015.8	015.2	015.0	016.7	016.0	013.9	015.6	014.4
Athens... ...	018.0	016.6	013.9	013.1	013.4	012.5	011.4	011.3	014.8	016.7	016.9	016.0	014.6
Cairo	019.9	015.3	015.9	014.1	012.8	012.3	009.5	009.8	013.3	016.2	016.6	019.7	015.1
Bombay ...	015.5	014.5	012.8	010.6	009.1	005.2	005.1	006.9	009.5	011.7	013.8	015.5	010.8
Colombo ...	010.4	010.4	009.5	008.3	007.9	008.2	008.8	008.8	009.5	009.4	009.4	010.0	009.3
Batavia ...	009.9	010.0	009.9	009.3	009.5	009.9	010.3	010.5	010.7	010.2	009.9	009.6	010.0
Perth	013.1	013.4	015.6	018.4	018.5	017.8	019.4	018.8	017.9	016.9	015.7	013.6	016.6

(*Note.*—The figure 1 has been omitted in front of all readings over 1,000.)

These are normal values taken from the "Reseau Mondial."

TABLE 2.

SHOWING MEAN SEA LEVEL TEMPERATURES IN °C. ABSOLUTE (T_z).

	Jan.	Feb.	March.	April.	May.	June.	July.	Aug.	Sept.	Oct.	Nov.	Dec.	Average.
Greenwich ...	**276.6**	277.3	278.8	281.9	285.1	288.7	290.6	290.2	287.6	283.2	279.3	277.2	283.1
Marseilles ...	280.0	281.6	282.7	286.0	289.3	292.9	295.4	295.0	292.4	288.1	283.5	280.3	287.2
Rome	280.3	281.5	283.5	286.7	290.7	294.6	297.4	297.1	294.0	289.8	284.7	281.3	288.5
Athens... ...	281.6	282.4	284.9	288.4	293.1	297.4	300.4	300.2	296.9	292.7	287.3	283.8	290.7
Cairo	285.6	287.0	289.5	294.0	298.1	300.0	301.1	300.5	298.8	296.6	292.0	287.6	294.3
Bombay ...	297.1	297.2	299.4	301.4	**302.8**	301.6	300.2	300.0	300.0	300.8	300.3	298.1	299.9
Colombo ...	299.3	300.0	300.9	300.2	301.4	300.7	300.5	300.7	300.7	300.2	300.1	299.4	300.5
Batavia ...	299.0	299.0	299.4	299.8	300.0	299.5	299.2	299.5	299.9	300.1	299.8	299.2	299.6
Perth	296.0	296.5	294.8	292.1	288.9	286.6	285.7	286.3	287.5	289.0	291.6	294.6	290.7

These are normal values taken from the "Reseau Mondial."

TABLE 3.

SHOWING NORMAL MEAN VALUES OF THE FACTOR $(P_z/T_z \times 282/1014)$.

	Jan.	Feb.	March.	April.	May.	June.	July.	Aug.	Sept.	Oct.	Nov.	Dec.	Average.
Greenwich ...	**1.021**	1.019	1.011	.999	.990	.975	.972	.972	.982	.997	1.010	1.018	.996
Marseilles ...	1.009	1.003	.996	.984	.974	.986	.955	.957	.966	.979	.995	1.008	.983
Rome	1.009	1.005	.994	.983	.970	.959	.949	.950	.961	.975	.990	1.003	.978
Athens... ...	1.005	1.001	.990	.977	.961	.946	.936	.937	.950	.966	.984	.996	.970
Cairo	.993	.983	.976	.959	.945	.938	.932	.935	.943	.953	.968	.986	.959
Bombay ...	.960	.949	.940	.932	**.927**	**.927**	.931	.933	.935	.935	.939	.947	.937
Colombo ...	.939	.937	.933	.934	.930	.932	.933	.933	.933	.935	.935	.938	.934
Batavia ...	.939	.939	.938	.935	.935	.938	.939	.938	.937	.936	.937	.938	.937
Perth	.951	.950	.958	.969	.980	.987	.992	.989	.984	.978	.968	.957	.972

TABLE 4.

DIURNAL TEMPERATURE VARIATION (°F.).

Hour.		2.	4.	6.	8.	10.	12.	14.	16.	18.	20.	22.	24.
Kew (Summer)	...	56.5	55.5	57.0	60.8	64.2	66.8	68.5	68.7	67.5	63.6	60.2	58.0
(Winter)	...	37.8	37.6	37.5	37.4	38.7	40.7	41.7	40.9	39.6	38.9	38.5	38.1
Rome (Summer)	...	69.3	67.5	68.7	75.6	82.0	85.3	85.1	83.3	80.1	76.6	73.8	71.8
(Winter)	...	40.6	40.3	39.6	39.7	43.2	47.8	49.8	49.5	46.6	44.6	43.0	41.7
Cairo (Summer)	...	73.0	71.2	70.8	75.6	82.6	88.4	91.9	92.8	90.4	84.5	79.2	75.6
(Winter)	...	52.2	51.1	50.1	51.3	57.0	62.4	64.9	64.3	60.6	57.6	55.5	53.6

various parts of the world are comparatively scanty. In R. and M. 509* mean figures are given for England, Europe, Canada and the Equator, with the reservation that those relating to the Equator are very doubtful owing to the paucity of the observations. For the want of better figures, however, the Equator values will be taken as indicative of mean conditions at Bombay. Considering the representative case of an airship having a ceiling of 5 kilometres in England, it would appear *that if the lift of this airship were made the same in Bombay* it would only have a ceiling in that locality of 4.39 kms. in the average case or 4.0 kms. in the extreme case, approximately.

In addition to the seasonal variations in pressure and temperature at various places there are diurnal variations. The mean hourly variation of temperature at several localities is given in Table 4.

The diurnal variations in pressure are very small and usually masked by depressions, anticyclones, etc. Taking therefore the normal mean value of the pressure as given in Table 1, the following values will be obtained for the diurnal variation in the lift factor $P_z/T_z \times 282/1014$. (Temperatures in Table 4 must be converted into °C. to give T_z.)

TABLE 5.

DIURNAL VARIATION IN LIFT FACTOR.

	Minimum in middle of day.	Maximum at night.
Kew (Summer)	.9074	.9292
(Winter)	.9528	.9601
Rome (Summer)	.8806	.9084
(Winter)	.9383	.9543
Cairo (Summer)	.8696	.9028
(Winter)	.9133	.9385

N.B.—It will be seen that in spite of the differences in the mean lift factor as given in Table 3, a ship has practically the same lift at Cairo at night as it has in England in the day in summer time. There is about a 1.4 per cent. reduction at Cairo in the winter time. (This, of course, neglects superheating, which will be greatest in the day time.)

The question of diurnal variation in temperature at different heights will be discussed in greater detail later, but it is necessary at this point to draw attention to the fact that the value of the lift factor $P_z/T_z \times 282/1014$ is, in general, high at night and low during the day. Always presuming that the airship has to work to the same ceiling, it it will be seen that it is of advantage for the airship to depart on a journey at night time because it is enabled to leave with a greater load. The fall in the lift factor during the day is compensated for by the weight of petrol burnt if hydrogen is not also being burnt in the engines.

Effect of Alteration in Air Temperature

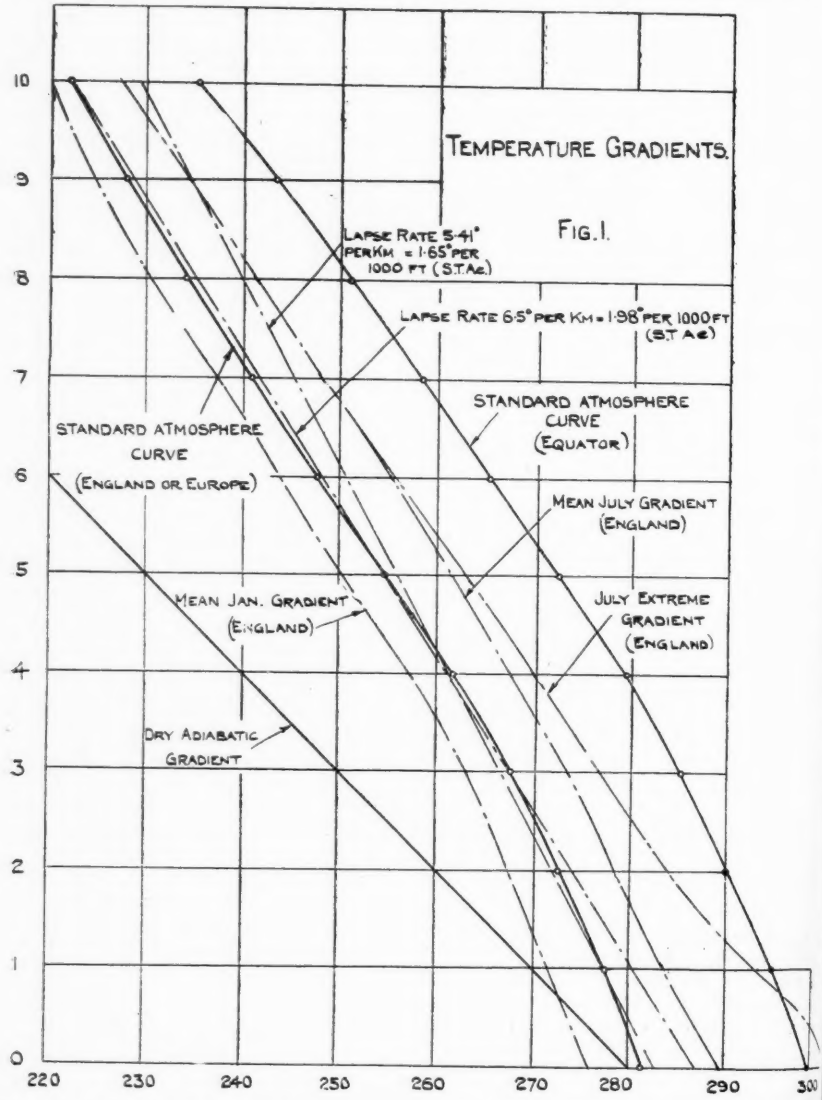
So far, no account has been taken of any difference between T_g and T_a, *i.e.*, superheating. Such a difference will practically always exist. This difference will, in most cases, be constantly varying and hence it will cause the lift of the airship to vary in like manner.

It will be seen that the variable portion of equation (i.) may be represented by $k(T_g - T_a)/(T_a)$ where k is some constant. Let $T_g - T_a = T_s$, *i.e.*, the number of degrees of superheat. If the gas temperature is higher than the air temperature T_s is positive and the airship has "false lift." If T_g is less than T_a then T_s is negative and the airship has "latent lift."

Percentage variations in the numerator of the above expressions are greater than those in the denominator. Consider first the variation in T_s due to variations in T_a (T_g remaining constant).

* *Loc. cit.*

The temperature of the atmosphere (T_a) varies with altitude, and at any given altitude it undergoes a seasonal and diurnal change. Some examples of the mean variation with altitude are shown in Fig. 1. If the atmosphere is not being heated by the surface of the earth and if it has been well stirred up, the maximum tem-



perature gradient which can exist amounts to about 10°C. per 1,001 metres in dry air. This is shown as the " Dry Adiabatic Gradient." This gradient will only be experienced on rare occasions chiefly near the surface on bright sunny days in spring and summer. It will be seen that the mean standard atmosphere

gradient for England and Europe is rather less, being 5.41°C. per km. up to 3 kms., and 6.5°C. per km. from 3 kms. to 11 kms. (The S.T.Ae. Law assumes a constant gradient between certain levels, and is, in fact, based on these numerical values.)

It will be seen that seasonal variations on the average do not affect the gradient, although they do affect the mean sea level temperature. At the Equator the mean gradient is slightly steeper and the mean sea level temperature, of course, considerably higher. These observations must, however, be accepted with reserve.

The actual temperature gradient never conforms to these mean values throughout any particular day, and on occasions it may become completely inverted (*i.e.*, there is a rise in temperature with height instead of the normal fall). It is outside the scope of this paper to deal with this matter in any great detail, but the salient points may be indicated.

When the earth is imparting heat to the air to any considerable extent, abnormal gradients of greater value than that given by the " Dry Adiabatic " are experienced. One example of such a gradient very close to a hot dry sandy surface is given in Table 6. This actual case was sufficient to produce the conditions of mirage.

TABLE 6.

Height above the earth's surface (ft.)	...	0	·5	1·5	2·5	3·5	4·5	5·5	6·5
Temperature (°F.)	...	85.5	83.0	81.1	80.4	79.9	79.9	79.9	79.9

At Pulham, during the airship mooring mast trials in 1921, on several occasions a difference in temperature between the top and bottom of the mast (100ft.) of as much as 10°F. was observed. This was at about 9 a.m. Usually by 10 a.m. the temperature had risen for the whole height and the abnormal gradient had disappeared.

At night the earth cools owing to re-radiation, and if it is clear, bright (*i.e.*, there are no clouds to re-radiate or reflect radiation back again) and reasonably dry, this cooling will produce an inversion of temperature. If moisture is present in the atmosphere it almost invariably acts as a " flywheel " on temperature change and hence may prevent the inversion. In hot dry climates big inversions may be expected, and the deposition of frost on the desert at night is a well-known phenomenon. Inversions may similarly be expected in the polar regions. The summer of 1921 was exceptionally dry, and big inversions were recorded at the Pulham mast. These more or less purely diurnal variations are dealt with more fully in Appendix II. It is only necessary to add here that they do not appear to have any effect on the atmosphere above a height of about 2 kms.

It will be seen that if the altitude of the airship is altered so rapidly that no heat transference takes place between the outside and the inside, superheating will take place at the rate of between 1.98 and 1.65°C. per 1,000ft. alteration in altitude if " standard atmosphere " conditions exist. It is necessary, however, to draw attention here to a secondary effect which will cause superheating when the change of altitude is so rapid as to be adiabatic. The compression or expansion of the gas will alter its temperature. The change is analogous to the formation of the " Dry Adiabatic Gradient " in the atmosphere and is calculated in the same manner. Since this temperature change in the gas is not directly concerned with meteorological factors it has been dealt with in an Appendix.

In Appendix I. it is shown that the gas temperature will rise at the rate of 3.07°C. per 1,000ft. descent. The net superheating in a standard atmosphere will therefore be between 1.09 and 1.42°C. per 1,000ft. descent. In the following example an airship of two million cubic feet capacity with a ceiling of 15,000ft. has been considered. The false lift gained at sea level by adiabatic descent from various heights in a standard atmosphere is shown in Table 7.

TABLE 7.

Descent from (ft.).	15,000	13,000	11,000	9,000	7,000	5,000	3,000
False lift at sea level (lbs.)	7,502	6,820	6,070	4,979	3,921	2,830	1,773

These values will never be realised in practice, but they indicate the possibility of making a safe landing with an airship which is " heavy " by bringing it down sufficiently rapidly. Cases are on record in which this manœuvre has been carried out successfully.

If alteration is made in the altitude of the airship sufficiently slowly to avoid the heating or cooling of the gas by compression or expansion, such alteration may still not be sufficiently slow to allow the gas temperature to follow the air temperature. In such a case an airship which is in static equilibrium at a certain height will become heavy by descent or light by ascent, if the normal type of gradient exists. This is an unstable condition which calls for close attention by the pilot if there is a large positive temperature gradient. On first leaving the ground it is always advisable to fly at the normal height for some considerable time before any attempt is made to judge the static equilibrium of the airship. On preparing to land it is likewise advisable to ask for the ground temperature, and if a fairly large gradient exists, the airship should be brought down very slowly or else sufficiently light to balance the negative superheat which will occur. During the experiments at Pulham, at the period when a heavy gradient was level with the top of the mast, the ship became very unstable. If the tail dropped, the airship passed into warmer air and became " heavy." If ballast was released, the tail rising into colder air, tended to rise still further. During such a period the ship had to be carefully watched or she would oscillate through quite large angles. If a fair wind was blowing, this trouble naturally did not exist.

An inverted gradient will change the unstable condition referred to above to a very stable one, making piloting almost fool-proof, it being possible to " sit " in the top of the inversion with practically all engines stopped.

Special temperature conditions are brought about by vertical currents of air. The vertical currents usually consist of a hot stream of air rising or a cold stream falling. In flying into such a current the airship will experience a " dunt." The " dunt " received will depend on two actions—one the dynamic action of the current, and the other the sudden change in lift due to change in temperature. In general the two actions will oppose one another. The matter is discussed further later, in the consideration of dynamical effects, but attention may be drawn here to an idea common in the minds of many pilots, and which would appear to be a fallacy. On a day when large detached cumulus clouds exist it is a common experience for pilots to find their ship immediately becoming heavy in the shelter of a cloud, but regaining its lift very quickly on leaving this shelter. The explanation of this phenomenon usually expressed is that the gas cools in the shelter of the cloud and heats up again immediately on leaving this shelter. It is felt that this explanation cannot be correct as there is very definite evidence that the gas takes a considerable time to respond to temperature alterations in the envelope or outer cover (*vide* Appendix II.). The true explanation probably lies in the fact that a large detached cumulus cloud may mark the top of a slowly-rising column of warm air and the change in lift in the airship is due to an alteration of air temperature rather than of gas temperature.

Winds

Special temperature gradients and inversions are brought about by winds. It is not unusual to find an inversion in the edge of an anticyclone or in the trough of a depression. A change in wind direction with height will be accom-

panied, as a general rule, by a steep gradient. Increase in temperature will probably point to a westerly or southerly wind and decrease to a northerly or easterly wind; moreover, the change in wind direction will probably be accompanied by a cloud strata. If, therefore, on passing through such a strata a steep gradient is experienced, it is fairly safe to assume a change in wind direction, and the nature of the gradient should give an indication of the nature of the change. A typical example is provided by the summer conditions in Egypt. There is a persistent northerly wind at the surface during the summer and early autumn. The height of this wind is limited. A belt of calm usually overlies it, followed still higher by westerly winds. The height of this transition is on the average a little above the 2 km. level. As might be expected, the transition is often accompanied by a marked inversion of temperature.

Effect of Alteration in Gas Temperature

So far, the variation of T_g has only been considered as due to variation in T_a, except for the fact that the alteration in T_g due to rapid expansion and contraction has been noted. T_g will practically always differ from T_a owing to radiation, and the amount of this difference will depend on the nature of the outer cover or envelope, and the intensity of the solar radiation which is incident on it. There will be what may be described as a " green-house " effect. The effect of solar radiation on balloons has been dealt with in an admirable paper by J. D. Edwards and M. B. Long.* The radiation characteristic of fabrics has been dealt with in a later section of the present paper. The rise in temperature of the fabric of an airship above that of the surrounding atmosphere appears to be always proportional to the solar intensity. It is therefore of advantage to fly low where the solar intensity is least in order to minimise superheating. If the gas is thoroughly circulated within the envelope, it should be at the same temperature as the mean temperature of the fabric when equilibrium conditions have been established. How thorough the circulation of the gas may be depends on the direction of maximum incident radiation. If the sun is directly above the airship it will tend to set up stratification, *i.e.*, there will be a temperature gradient from the bottom to the top of the gas, which is a fairly stable condition. If, on the other hand, the sun is on the beam, rotary convection will be set up in the gas which will tend to make it gather more heat from the fabric and hence the superheating will be more serious. This is found to be very decidedly the case in practice. It should follow that in equatorial latitudes, where the sun is more vertically overhead than in Engand, there will be less heating of the gas by circulation over the hot fabric. An important question is the rate at which the gas temperature will follow variation in the sun's intensity in the case of various sized airships. This has a definite bearing on the relative amount of superheating to be expected in various sized airships. This, and other matters connected with it, such as the cooling effect of the air passing over the surface of airships, have been dealt with in Appendix II.

There is need of more accurate data such as true mean gas and air temperatures in flight under various conditions. So far the gas temperature has been measured by an electrical thermometer slung in the centre of one of the gas-bags. It does not follow that the mean temperature is necessarily that at the centre of the bag; in fact, it will be seen that there are reasons why this probably gives a value which is too low; moreover, measurements in all the gas-bags (in the base of a rigid airship) are necessary in order to obtain the true mean for the

* Technologic Papers of the U.S.A. Bureau of Standards No. 128.
See also—
Bassus and Schmauss, Zs.f. Flugtechnik, pp. 216, 295, 191, 258, 1912; 297, 1913; 79, 1914.
Stern, Zs.f. Flugtechnik, p. 145, 1915.
Emden, Zs.f. Flugtechnik, p. 315, 1912.

whole ship. Attempts have been made to measure the difference between gas and air temperatures directly by means of a differential thermo couple, but it would appear that more exhaustive and reliable information would be obtained by measuring the absolute values of the gas and air temperatures separately.

Humidity Effects

As there appears to be a lack of uniformity in the methods employed in finding the correction to be applied to the lift of an airship for humidity, this matter has been dealt with in Appendix III. It is there shown that the *correction* may be expressed in the following form for all practical purposes :—

$$-\frac{\text{Total capacity}}{1000} \times \underset{(\text{at } P_z\ T_z)}{\text{percentage full}} \left\{ \frac{282}{1014}\,\frac{p_s}{T_s}\,\text{purity}\,(78.2\,H_a - 5.43\,H_g) + \left(\frac{T_g - T_a}{T_a}\right) \frac{p_s}{T_s} \times \frac{282}{1014} - A_z\,(H_a - H_g) \right\}$$

H_a = relative humidity of air.
H_g = ,, ,, gas.
p_s = tension of aqueous vapour in saturated air at temperature T_z (in millibars).
A_z = absolute humidity in lbs. per 1,000 cu. ft. in saturated air at temperature T_z.
Purity = true purity of the gas with the air at H_a saturation and the gas at H_g saturation.

Taking a two-million cub. ft. ship completely full and purity 100 per cent., the following values will be obtained for this correction if superheating is ignored and the air temperature is taken as 282°C. abs.

p_s (at 282°C.) = .34″ mercury = 11.5 millibars.
A_z (at 282°C.) = .54lbs. per 1,000 cu. ft.

TABLE 8.

H_a (%)	0	100	0	100	50	50	100	
H_g (%)	0	0	100	100	50	100	50	
Correction in lbs. ...	0	−680	−960	−1640	−820	−1300	−1160	

Variations in humidity are most important in the summer months. In climates such as that of England the absolute amount of moisture in the lower strata of the atmosphere increases with it, so that the diurnal variation is in the reverse direction to the temperature. In climates such as that of Egypt, the absolute amount of moisture keeps fairly constant and therefore the relative humidity is inversely proportional to the temperature. Some examples of the diurnal variation of humidity are given in Table 9. Taken in conjunction with Table 8, these will give an idea of the effect which this variation has in the lift of the airship.

TABLE 9.

MEAN DIURNAL VARIATION OF RELATIVE HUMIDITY (PER CENT.)

Hour	2	4	6	8	10	12	14	16	18	20	22	24
Kew ...	87	88	85	76	67	62	59	58	61	71	79	84
Paris ...	90	92	88	75	63	56	54	54	59	72	81	86
Cairo ...	63	60	68	63	49	37	31	30	35	44	52	58

In general, as has been stated, the relative humidity is low when the temperature is high, and hence the effects on the density of the air (and therefore the

lift of the ship) tend to neutralise one another. It is possible to find regions where high humidity and high temperature go together (*i.e.*, in the doldrums), and here the effect on air density causes a serious reduction in lift. Continuous records of humidity are difficult to make, the hair hygrometer being about the only instrument which has been devised for this purpose. Such an instrument does not function well at low temperatures, but fortunately, as far as the atmosphere is concerned, the region of low temperature, *i.e.*, great altitude, has very little moisture. For obtaining the humidity in the interior of gas-bags, a distant-reading instrument requires to be developed unless use is made of a continuously recording hair hygrometer, which can only be read at the end of a journey and is difficult to put in or out of the bag. The gas, when it is first fed into the airship, is probably highly saturated, but there is a certain amount of evidence that this high degree of saturation does not remain for long. It appears that a transference of moisture takes place from the inside to the outside of the bag or *vice-versa* at a reasonably rapid rate. Apart from any question of lift, the amount of moisture in the gas-bags has an important effect on their physical condition.

No reliable measurement of the weight effect of rain on an airship has been made so far in England. This effect is naturally less in a wind than in stagnant air, but in either case it rapidly reaches an equilibrium value. The maximum heaviness caused in R.33 at the mast by rain appears to have been about 1.5 tons.

Hail is rather more serious than rain because of its marked dynamic effect. Generally both rain and hail can be avoided by alteration in height. Snow may, under certain conditions, cake on the bow of the ship and drive it down owing to its weight.

It is, however, only the soft wet snow that tends to cake, and by rising 1,000 feet or more dry snow will be encountered which will not tend to collect on the ship. There is an electric effect felt from flying through dry snow, and the ship is apt to become highly charged, so that it is always advisable to pull up the aerial under these conditions.

Ic *Winds and their Effect on Course*

Various mathematical and graphical methods have been devised for estimating the most economical speed at which an airship can be flown through a wind. As the most important consideration will usually be that of making a journey in a scheduled time, these methods may be dismissed as being of academic rather than practical interest.

Various notes on flying through winds have been published by one of the authors of this paper elsewhere, but they are included here for the sake of completeness.*

Strong winds are caused chiefly by depressions or cyclones. These cyclones are approximately circular in form with the wind blowing round them in a counter clockwise direction with a slight bearing towards the centre or low pressure.

They vary very considerably in size, and may cover half the Atlantic or be only 200 miles in diameter. The larger the depression the longer warning we have of its approach, and therefore the easier it is to avoid or utilise.

Also, except in rare cases, a very large depression is only associated with very high winds over a comparatively small area.

The strength of the wind is largely dependent upon the distance apart of the isobars. The shorter this distance the stronger the wind. It is obvious, therefore, that where the winds are strong and the isobars close together the area covered must be small.

* *Vide* Scott. Aero Jour., Feb., 1921.

Thus a pilot, on meeting a strong wind, turns broadside on to the wind, and in a very short time he will be through the bad zone and in a light or favourable wind. It will be seen that the time taken for the ship to cross the bad weather zone does not depend on the strength of the wind but upon the speed of the ship; also that the amount the ship drifts out of its course depends, on the other hand, on the time taken and the speed of the wind. The airship must, of course, have a sufficient air speed to prevent its being driven too far out of its course.

Except in very rare circumstances, such as when the base at which the pilot wishes to land is in the bad weather zone, a pilot should never beat directly into a strong wind, and even in the above case it often pays to lie off for a few hours, as the movement of the centre of the depression will move the area of strong wind away from the base.

It is owing to this movement of the centre of a depression that, except in exceptional circumstances, a very strong wind does not blow for very long in one place.

A much more difficult wind for the airship pilot to deal with is a head or beam wind of from twenty to thirty miles per hour, as this may blow over a comparatively large area and for long periods.

In order to deal with this wind, good meteorological reports must be at the pilot's disposal, and he must vary his course sometimes 12 to 24 hours ahead in order to circumvent such a wind. As an example, the pilot is flying from Malta to Norfolk; there is a large depression centred N.W. of Scotland, giving a westerly and south-westerly wind over the South of England and North of France. If the pilot endeavoured to make good a direct course from Malta to England he would be obliged to edge up into a thirty-mile broadside wind over several hundred miles, and the time taken for the journey would be greatly increased.

If, however, the pilot was supplied with good meteorological information, he would set his course so as to pass out into the Bay of Biscay, just north of the Pyrenees, and when he encountered westerly winds of increasing force he would turn north at right angles to the wind and use the drift to make his base. Thus during no part of his journey would he be heading into a wind, and although the course taken is somewhat longer than the direct route, the time taken will be very little in excess of the still air time, and with a reasonable amount of spare engine power the airship could still make its scheduled time on the journey.

At the present time there is not a great deal of data regarding the variation of wind velocities and direction with height. Such data as is available chiefly deals with anti-cyclonic conditions when the air is clear and a pilot balloon can be sent to a great height. This is the fine weather condition, when the need for alteration of altitude to avoid bad winds is rarely necessary.

The cyclonic conditions over the British Isles are nearly always associated with comparatively low heavy clouds, when it is impossible to follow a pilot balloon to any height, and it is under these conditions that further data is required.

General experience tends to show that westerly winds increase with height, whereas easterly winds tend to decrease, both tending to turn anti-clockwise.

The permanent winds of the world may be divided into two classes—(1) the easterly or trade wind, which blows north and south of the equator in easterly direction and towards the equator; (2) the westerly drifts, which are found in the Arctic and temperate zones.

The principal westerly drifts are in the North Atlantic, where they are modified and interrupted by the cyclones which pass over this region, and the great westerly drift round the Antarctic Continent, which affects the southern part of the South Atlantic, the Indian Ocean and the South Pacific ocean.

There are also many smaller permanent winds and also seasonal winds, such as the monsoons.

Although the area of the trade winds is well known and well defined, very little is known except of the surface winds, and it is very important that further investigations should be carried out to find to what height these winds extend and if there is a return westerly wind at any reasonable height.

Over the West Indies the greatest force is found at between 2,000 and 3,000 feet, and a falling off in wind velocity occurs above this. It is probable that well clear of land the greatest velocity is even lower, and comparative calm or a return or trade reversal wind will be encountered at no great height.

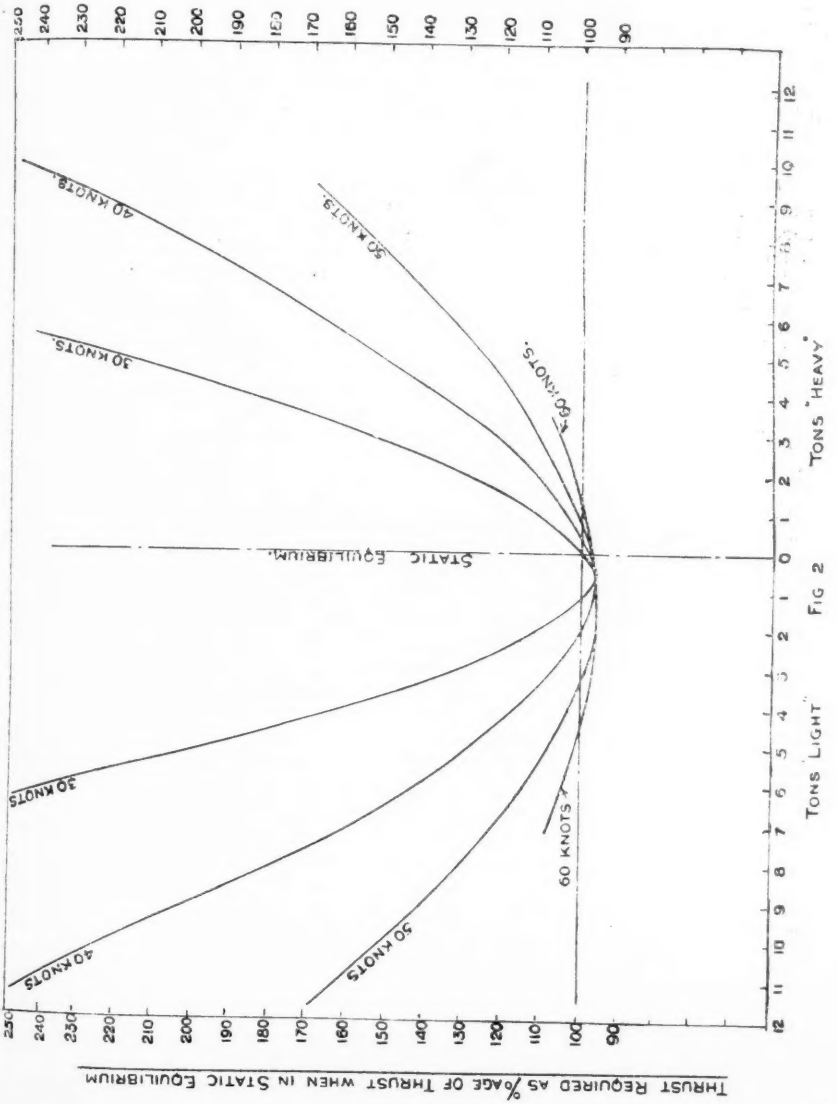

THRUST REQUIRED AS % AGE OF THRUST WHEN IN STATIC EQUILIBRIUM
250 240 230 220 210 200 190 180 170 160 150 140 130 120 110 100 90
STATIC EQUILIBRIUM
40 KNOTS
30 KNOTS
50 KNOTS
60 KNOTS
TONS LIGHT
TONS "HEAVY"
0 1 2 3 4 5 6 7 8 9 10 11 12

FIG 2

It is obvious that any regular service by airships should be planned so as to take the maximum possible advantage of these winds.

Convectional winds and currents will be briefly referred to later in relation to their dynamic effect. These winds, compared with the permanent winds, are very local; they are met with all over the world, and are due to the uneven heating of the earth's surface. Land and sea breezes are of this class; also the permanent northerly wind over Egypt. Convectional winds are met with in the Atlantic where the gulf stream and Labrador currents travel parallel to each other. They are of distinct use to the pilot who understands them and knows how to make use of them, but owing to their small area they are, of course, of small importance compared to the permanent winds.

1b *Dynamical Behaviour*

The dynamic forces acting on a body moving through the air are proportional to the density of the air and the square of the velocity. From this it will be clear that it is safer to manœuvre an airship at high speeds at considerable altitudes rather than near the ground.

Reduction in density of the atmosphere, therefore, whether it be due to change in altitude or in climatic conditions, will reduce the resistance of an airship and hence the dynamic lift for a given speed and altitude. Superheating cannot be economically dealt with as a rule by valving or releasing ballast, and therefore the "altitude" of the ship has to be altered in order to bring a vertical dynamic component into play. The variation in thrust required to maintain a given speed for various degrees of "lightness" or "heaviness" for an airship of the R.33 class is shown in Fig. 2. It will be seen that the greater the departure from static equilibrium the greater is the speed at which it is most economical to fly. An additional reason for flying fast when there is considerable superheating is in order to obtain the maximum cooling effect from the air. With increase in size of ship, the false lift due to a given degree of superheating is proportional to the capacity. If the same percentage weight of machinery is employed, the dynamic lift (expressed as a percentage of the displacement) varies as (capacity) 8/9 so that practically the same degree of superheating can be dealt with.* The same percentage weight of machinery would give higher speeds, however, with increase in capacity. If the same speed is maintained with increase in size, the degree of superheating which can be dealt with will be less. This is an important point to be considered in connection with flying large airships through equatorial regions. The amount of ballast required to deal with superheating may be very serious unless there is an increase in speed with size of ship.† As a general rule the causes which lead to strong superheating lead to low air density and hence reduced dynamic forces. This state of affairs is typical of high altitudes in the equatorial regions, and it is therefore advisable to fly as low as convenient. The effect of decreased density, humidity, etc., on the behaviour of engines has been dealt with very fully elsewhere, and as this is not a matter which is peculiar to airships, it is outside the scope of this paper.

The effect of vertical currents of air or "dunts" has already been briefly referred to. There will be a dual effect when an airship enters such a current—the alteration in temperature will alter the lift of the airship by an amount proportional to the capacity of the ship, and the current will exert a dynamic force on the airship by an amount proportional to the (capacity) 2/3. In general the two effects will act against one another. It can be shown that if air is flowing transversely across the hull of a modern rigid airship in the vertical plane, the airship will tend to turn its nose away from the direction from which the air is flowing.‡

* *Vide* Scott. Aero Journal, Feb., 1921, p. 50.

† It will be seen, however, in Appendix II., that there are other reasons why the superheating in large airships may be expected to be proportionately less than in small ones.

‡ *Vide* Scott. *Loc. cit.*

On flying into a vertical current the nose of the airship will point down or up according as the direction of flow of the air relative to the hull is downwards or upwards. Imagine that the nose points downwards but the airship falls; the relative motion of air is downwards. Since the airship is falling more slowly than the current, but nevertheless *is* falling, the dynamic effect is greater than the false lift gained by flying into a cold current. (A downward current will in general be a cold one.) It will be seen that it is possible to gauge the nature of the disturbance from the behaviour of the airship. Since dynamic disturbances are proportional to (capacity) 2/3 they will tend to become of relatively less importance with increase in size. In flying beneath clouds which mark the apex of vertical currents of air, it may be expected that there will be a particular altitude at which the dynamic and temperature effects are equal and opposite, and therefore very little disturbance is experienced. This is found to be the case in practice.

A study has been made of gusts and bumps in Egypt. The authors are indebted to the Meteorological Office for this information, which may be briefly summarised as follows :—

There is a well-marked diurnal variation in gustiness which starts at about 9.0 a.m., reaches a maximum during the middle of the day, and dies away at sunset. Since the wind is often at its maximum at about sunset it would appear that gustiness cannot be due to wind alone, but must be the result of vertical currents. The wind blowing steadily at about, say, 12 m.p.h. from the N.N.W. will suddenly die and then spring up again from the west, remaining steady for some minutes and then again altering in direction. Although these changes in direction are fairly sudden, they are not likely to cause damage to a ship moored out, as they occur chiefly when the wind is light. As far as bumps or "dunts" are concerned, the day may be divided into a period from 6 p.m. to 9 a.m. when there is no vertical motion of the air, and a period 9 a.m. to 6 p.m. when there are stray occasional currents and generally disturbed conditions. The bumps appear to be of three kinds :—

(*a*) Disturbed air. Air thoroughly churned up does not appear to extend above 3,000 to 4,000 feet. It would make an aeroplane roll, but would have no noticeable effect on a large airship.

(*b*) Small vertical currents. These are due to comparatively small bodies of air becoming superheated and rising quickly, and by corresponding bodies of cold air flowing down to replace them. These give rise to a bump lasting from one to three seconds, and except over hilly country (where their vertical speed may be as much as 1,000 feet per minute) they will not alter the height of an airship, but will probably make it pitch badly.

(*c*) Large vertical currents. These may have a speed of 300 to 400 feet per minute and may cover an area of at least half to three-quarters of a mile in diameter. These would make the landing of an airship in the heat of the day rather difficult. The bumps do not appear to extend above the limit of the haze-horizon or inversion, which has been referred to earlier as marking the boundary of change in wind direction.

2 *Effect of Meteorological Conditions on the Choice of Sites for Aerodromes*

The meteorological effects which have been discussed in section (1) will automatically suggest the factors which govern the choice of aerodrome sites. It is, therefore, only necessary to summarise the salient points.

Wind

A complete absence of wind is not an advantage. If the air conditions are too stagnant they are apt to break up in a disruptive manner, being accompanied by electrical storms and strong vertical currents and eddies.

For landing, either to a mast or landing party, a steady wind of about 10 to 15 m.p.h. is an advantage so long as its direction and force is reasonably steady. An area subject to morning and evening breezes, or an area subject to one of the permanent winds, such as the trade winds, is generally suitable.

Height

It is obviously correct to keep the aerodrome as low as possible, provided it can be efficiently drained and is reasonably free from fogs or heavy ground mists.

Temperature

It has been shown that the temperature substantially affects the lift with which an airship leaves the ground if it has to work to a given altitude. A low mean temperature is desirable. In general, it will be best for airships to depart on their journeys at night, and therefore a low night temperature is of more importance than a low mean, although this statement must be qualified by saying that an area where a large diurnal variation of temperature exists is usually troubled with rather bumpy conditions during the heat of the day. Very steep temperature gradients are undesirable, but inversions are an advantage.

Humidity

Maximum lifting conditions would be obtained from dry air, but it has been mentioned that moisture acts as a " flywheel " on temperature change, and hence, in general, prevents the formation of the undesirable steep gradients which have been referred to above. This is probably the most important effect as far as moisture is concerned, and hence the aerodrome should be in a reasonably moist locality. If the surface is too dry, dust and fine sand continuously blowing over an airship riding at a mast would not only be detrimental to machinery but would also produce quite marked electrical effects (*vide* section (3)).

3 *Chemical and Physical Effects Arising in an Airship's Structure from Various Climatic Conditions*

The most important items to be considered under this heading are the metal structure and the fabric gas-bags and outer cover. It is considered extremely unlikely that rigid airship hulls will be built of wood in the future, or that wood will be used for any appreciable extent anywhere in an airship's structure. For this reason it is not proposed to consider the special effects which arise in wood from change in climatic conditions.

Metal Structure

Change of temperature will cause no appreciable stress effect if the airship's structure is made of the same metal throughout. Airship hulls are at present constructed from a combination of duralumin girders and steel wires. The co-efficient of expansion of duralumin is nearly twice that of the steel, and hence if the temperature of the structure rises above the mean temperature at which it was assembled, stresses will be set up due to this cause. If, on the other hand, the temperature of the structure falls below that at which it was assembled, the steel wires will merely slacken. It will be seen that it is advisable therefore to assemble such a structure in the hottest possible weather, and in any case special stresses may be expected to be set up in the hull when flying with tropical temperatures.

The matter has been considered in some detail by Mr. E. H. Lewitt,* who

* *Vide* Lewitt, " Aeronautics," July 21st, 1921, p. 48.

arrived at the following values for a small rigid airship when the temperature range was 30°F.

TABLE 10.

Member.	Temperature Stress.	Working Stress in Material.	Percentage Increase due to Temp.
Radial wire	2,100 lbs./sq. in.	60,000 lbs./sq. in.	3·5
Circumferential wire	2,100 ,,	60,000 ,,	3·5
Diagonal wire ...	2,970 ,,	60,000 ,,	5·0
Transverse girder ...	770 ,,	8,000 ,,	10.0
Longitudinal girder	310 ,,	8,000 ,,	4.0

The working stress of the girders was obtained from their buckling stress as struts. The method employed was only approximate, but probably sufficiently accurate to indicate the order of stress to be expected. It will be seen from Table 2 that the probable maximum temperature range between the coolest time in England and the hottest time in Bombay is about 47°F. This would mean a percentage increase in stress in the worst case (*i.e.*, that of the transverse girder) of about 16 per cent., which is sufficiently serious to be taken account of with a low factor of safety. These stresses will be independent of the length of the members if they are all altered proportionately, but will not be independent of the cross-sectional areas, since it is improbable that these will also be altered proportionately with increase in the lineal dimensions of the airship.

The corrosion of the hull is a serious matter unless non-corrodible material can be used. There is no reason to suppose that this will vary appreciably with the climate in which the airship is operating, although the protectives used may not be equally effective in all climates. This matter is not peculiar to airships, however, and it is beyond the scope of this paper to discuss it further.

Fabric

There are several important characteristics of fabric, but it is only possible here to discuss them in relation to meteorological conditions. They may be summarised as follows :—

(*a*) Radiation characteristics.
(*b*) Permeability of gas-bag fabric to hydrogen.
(*c*) Permeability of gas-bag fabric to moisture.
(*d*) Surface tension of water in contact with cover.
(*e*) Conductivity and other electrical characteristics.

(*a*) *Radiation**

The radiation which is incident on the surface of the airship is partly absorbed, partly reflected and partly transmitted. Edwards and Long have measured this partition of energy in the case of a number of representative fabrics. Their results are reproduced in Table 11. The energy which is absorbed heats the fabric, which in turn supplies heat by re-radiation, conduction and convection to both the gas contained in the airship and the surrounding atmosphere. Let A_1 be the coefficient of absorption of the fabric in the region of maximum solar intensity (0.5 μ) and let A_2 be the coefficient of absorption of the fabric in the region of maximum intensity of the re-radiated energy, then it can be shown that $T=(A_1/A_2)^{\frac{1}{4}} \times (E_s/2\sigma)^{\frac{1}{4}}$ if the fabric is in a vacuum. The spectral region of the re-radiated energy is almost invariably principally beyond 4.5 μ, *i.e.*, in the infra red. E_s is the rate at which energy is incident on the surface and $(E_s/2\sigma)^{\frac{1}{4}}$ represents the temperature which would be attained by a totally absorbing black body. For minimum temperature of the fabric A_1 should be small and A_2 large. For transparent bodies A_1 is zero and radiation causes no rise in temperature. Of all opaque bodies examined so far, zinc oxide appears to have the lowest value of

* *Vide* Edwards and Long, *loc. cit.*

the factor $(A_1/A_2)^{\frac{1}{2}}$. The value is 66 per cent. The value of coatings containing aluminium powder does not lie so much in their low value of $(A_1/A_2)^{\frac{1}{2}}$ as in their high metallic reflection especially in the infra red region. Reference should be made to the paper by Edwards and Long* for further details on this subject.

TABLE II.

RADIATION CHARACTERISTICS OF BALLOON FABRICS AND THEIR INCREASE IN TEMPERATURE WHEN EXPOSED TO SUNLIGHT.

(Except where stated otherwise, all fabrics are of two-ply construction with an outer surface or coating of the character indicated.)

No.	Description of Fabric.	Radiation from Tungsten lamp after passage through 2.0 per cent. solution of $CuCl_2$. Reflection. Per Cent.	Transmission. Per Cent.	Absorption. Per Cent.	Radiation from sun solar intensity 1.4 Gm. cal per cm², per min. temperature rise above air temperature of 25° C. °C.
1.	Goodyear airship fabric after 60 days' exposure	54.6	0.0	45.4	22.1
2.	Goodyear airship fabric; aluminium coated	50.7	0.0	49.3	——
3.	Experimental airship fabric; aluminium coated	46.9	0.0	53.1	22.9
4.	Goodyear fabric; same as No. 1 before exposure	44.9	0.0	55.1	23.0
5.	Experimental airship fabric; aluminium coated	40.1	0.0	59.9	24.5
6.	Aluminium coated fabric; covered Nitrocellulose "dope"	32.4	1.4	66.2	——
7.	Aluminium coated fabric, dusted with talc	22.6	0.1	77.3	——
8.	Ballonet fabric, uncoated cloth surface	42.2	11.8	46.0	19.9
9.	Experimental single-ply fabric; pure gum coating	39.2	12.4	48.4	——
10.	French airship fabric; cloth surface dyed chrome (yellow 1916)	41.9	3.1	55.0	20.7
11.	Goodrich kite fabric; 30 days' exposure; light brown rubber coat	26.1	2.6	71.3	25.5
12.	Goodyear kite fabric; 30 days' exposure; light grey rubber coat	19.3	2.8	77.9	29.0
13.	Goodrich kite fabric No. 11 before exposure	19.4	2.4	78.2	30.0
14.	Fabric from model balloon used in this investigation	15.0	4.1	80.9	(40.4)
15.	N.S Rubber Co. kite fabric; 30 days' exposure; olive green rubber coating	12.1	0.6	87.3	32.4
16.	Experimental fabric; cloth surface dyed olive drab	6.5	3.8	89.7	34.1
17.	Experimental fabric; dark grey rubber coating	8.3	0.0	91.7	36.0
18.	Experimental single-ply fabric; black rubber coating	5.7	0.2	94.1	37.4
19.	Experimental fabric; dark green rubber coating	5.2	0.0	94.8	39.0

* *Vide* Edwards and Long, *loc. cit.*

XIIM

(*b*) *Permeability to Hydrogen*

The only important factor affecting the permeability apart from physical and chemical deterioration is rise of temperature. This has been studied in the case of rubber, but very little work seems to have been done in the case of goldbeaters' skin, which is the chief gas-holding medium used in the gas-bags of rigid airships. In the case of rubber the permeability increases by 4 to 5 per cent. per 1°C. rise in temperature. In cases where it is undesirable to valve gas on a voyage (*i.e.*, with helium, and in the case of hydrogen being required for burning in the engines) this effect is sufficiently great to be troublesome.

(*c*) *Permeability to Moisture*

It has been found that the permeability of fabric to water vapour is surprisingly high, *i.e.*, of the order of 2,500 times the permeability to hydrogen.* In the case of a two-million cub. ft. ship filled with gas 50 per cent. saturated flying into air which is 100 per cent. saturated it would take about 35 hours for equilibrium to be established, *i.e.*, for the gas to become saturated. The loss in lift due to this change would be about 500 lbs. in this time. The loss of lift due to leakage of gas in the same time would be about 1,500 lbs. These two effects may be additive or subtractive according to whether the gas is flying into air which is moister or dryer than itself. In any case the effects do not appear to be serious.

Some measurements made in R.36 are shown in Fig. 2A. The measurements of humidity inside a gas-bag were made with a recording hair hygrometer. The instrument was unfortunately placed close to the fabric of the bag and was therefore probably affected by the hygroscopic nature of the glycerine with which the goldbeaters' skins are dressed. The state of the atmosphere was fairly consistently humid the whole time owing to light rain and mist, and hence the range of variation was not sufficiently great to obtain reliable results. There appears to be little doubt, however, that there was a variation in the absolute moisture content of the bag and that the rate of change was greater than that indicated above. The figures given above were for multi-ply rubbered fabrics however. The gas-bags of R.34 were proofed with rubber but only in a very thin layer, and the governing factor is probably the glycerine-soaked goldbeaters' skin.

With the English method of constructing skin-lined fabric it is essential that the bags should be kept moist. The skins are put on to the fabric when they are wet and at their maximum extension. If the fabric subsequently becomes very dry, the skin contracts and the cotton expands. Pleats occur in the cotton over which the skin is stretched tightly. The consequence is that stresses are thrown on to the skin which make it crack badly. Exposure tests have shown that this effect is very marked in Egypt. The gas-bags will have to be artificially moistened or else constructed on a different principle. An alternative method of manufacture which suggests itself is for the skins to be first made up into a sheet which will be applied in its dry contracted state to cotton which is as tightly stretched as possible.

(*d*) *Surface Tension*

The weight effect of rain on a large airship is likely to prove quite a serious matter. It would seem, therefore, worth while to consider the production of a dope for the outer cover, the surface tension of which is of such a nature as to allow only a minimum amount of water to adhere to the cover. Preliminary attempts have been made to do this by incorporating linseed oil in the dope, but

* *Vide* Aeronautical Research Committee's Report, No. E.B. 61.

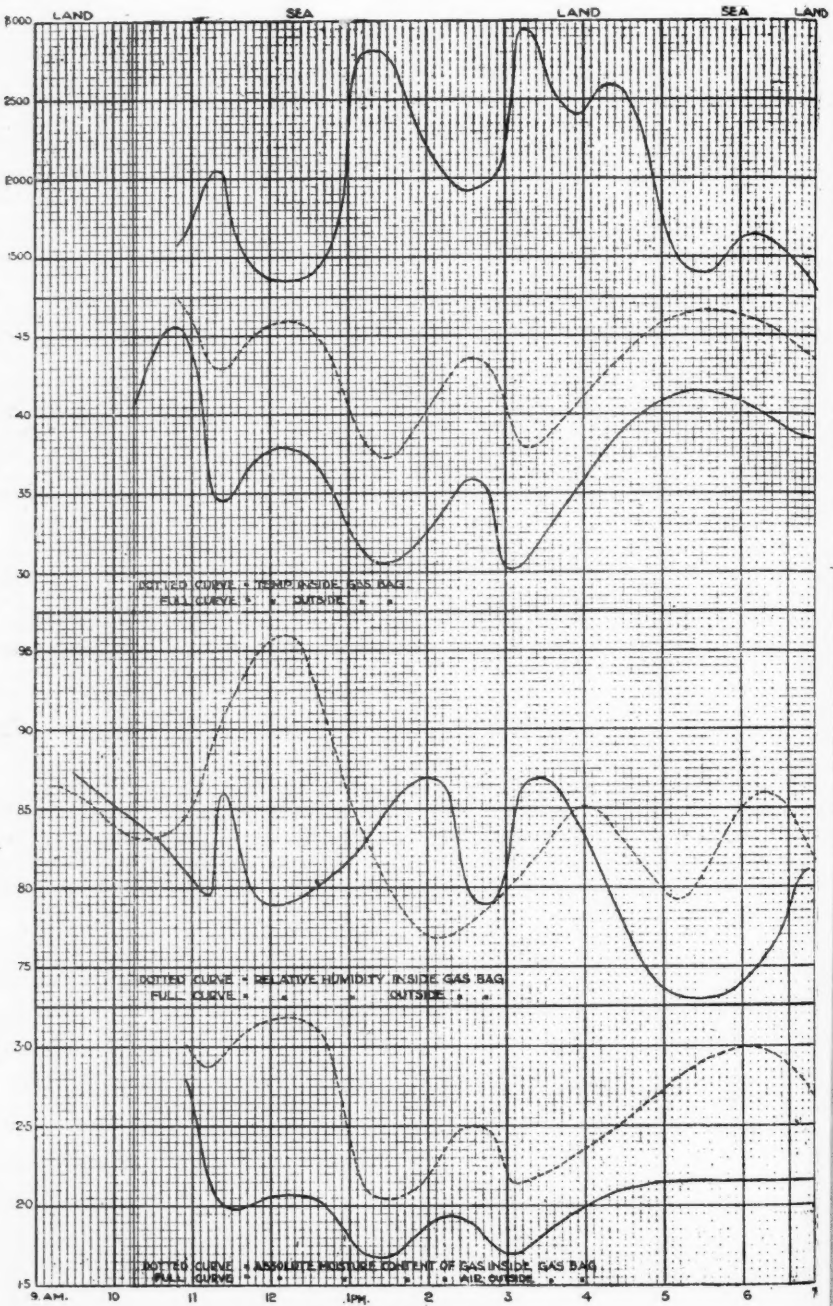

LAND
SEA
LAND
SEA
LAND
3000
2500
2000
1500
45
40
35
30
95
90
85
80
75
3·0
2·5
2·0
1·5
DOTTED CURVE = TEMP. INSIDE GAS BAG
FULL CURVE " " OUTSIDE " "
DOTTED CURVE = RELATIVE HUMIDITY INSIDE GAS BAG
FULL CURVE " " OUTSIDE " "
DOTTED CURVE = ABSOLUTE MOISTURE CONTENT OF GAS INSIDE GAS BAG
FULL CURVE " " " " " AIR OUTSIDE " "
9 A.M.
10
11
12
1 P.M.
2
3
4
5
6
7

FIG. 2A.

this is not a very satisfactory substance to have in contact with fabric. It is probable that better results could be obtained by the use of other oils or waxes.

(e) *Electrification*

The surface of an airship will become charged owing to the change of potential with height, or through flying through highly-charged cloud strata or through dry snow or sand. With regard to the last mentioned, quite violent sparking from the aerial of an aeroplane flying through a sand storm has been observed, and airships moored to masts or coming down to land will undoubtedly experience the effect in a sandy district. It has also been found that considerable changes in potential can be produced by the discharge of sand or water ballast. Sparking has been known to arise from the sudden separation of two surfaces, especially under frosty conditions. Friction of air on the cover and of escaping gas on the valves causes sparking which in many cases has proved fatal. Danger to the airship is principally in the discharges which occur when any part of the airship touches the earth or when the airship flies into a cloud strata at different potential. Efficient bonding of all metal parts is desirable in order to prevent local discharges, and it is now generally accepted that it would be of advantage to have the whole surface of the airship a continuous conductor. The majority of fabrics in general use are very poor in this respect. The best appears to be rubbered fabric which has had an exterior coat of aluminium powder printed on it. Even in this case the particles must be made to cohere electrically before any reasonable conductivity can be established. The resistance under these conditions becomes about 100 ohms for a strip 1 cm. by 1 cm.* The presence of moisture is important. It aids conduction very materially, and it was proposed by Von Sigsfeld that fabrics should be impregnated with some hygroscopic substance for this reason. This would probably be washed out of the envelope or cover, and in any case is not effective in dry weather. The glycerine with which gold-beaters' skins are treated probably performs this function as far as the interior of rigid gas-bags is concerned, and it has been stated that, apart from its other advantages, gelatine is a better material than rubber for sticking skins to fabric, because of its superior conducting power. It was found by the Electrification Committee (*loc. cit.*) that if a badly conducting fabric was wet on the inside it was liable to be punctured by spark discharges which travelled along the inner face, and for this reason the Committee strongly urge that the interior should be kept dry. It is unfortunately impossible to do this to any reasonable extent.

It appears to the authors of this paper that too little attention has been paid to the fact that owing to moisture, an envelope or gas-bag may virtually consist of two conducting surfaces separated by a thin layer insulating material between the inside and the outside; it becomes, in fact, a condenser of high capacity. It is true that De Founielle,† in commenting on the firing of a balloon, suggests that the balloon was virtually like a Leyden jar. The principal danger arising from this would seem to be when the fabric is torn or pierced by a conducting body. The inner surface will spark to the outer or *vice versa*, as it is possible for the two to be at a difference of potential which is high enough to cause a spark, but not necessarily high enough to puncture the insulating layer in the ordinary course of events. It is thought that this may provide an explanation of the fact that many balloons and airships have been fired by sparks caused when the fabric has been torn. A case occurred recently in America in which a non-rigid airship was blown against a shed door, which tore the fabric and fired the ship. The explanation which has been offered in the past of such accidents attributes them either to the fact that the airship comes into contact with an earthed body which is at a different potential to itself, or else that electrification

* *Vide* Report of Special Committee on Electrification of Balloons, Aero Research Committee.
† *Vide* Comptes Rendus, 1903 (1), p. 1415.

is caused by friction. If the first explanation is correct, it is difficult to understand why more accidents have not been caused by mere contact with an earthed body. The amount of friction which occurs normally would appear to be quite inadequate to make the second explanation feasible. If the above explanation suggested by the authors is true, a remedy suggests itself at once. The inner and outer surfaces should be bonded at many points (since conduction may only be in local patches). This might be carried out by incorporating a thin wire in the seaming cotton or by puncturing the fabric with conducting rivets in many places, or by chemical treatment of the insulating layer. This remedy forms the subject of a patent applied for by the inventors.

In conclusion, the authors desire to express their indebtedness to the Air Ministry for permission to submit this paper, and to Mr. M. A. Giblett of the Meteorological Office for assistance in collecting some of the data.

APPENDIX I.*

Superheating Caused by Adiabatic Change of Volume

If the altitude of an airship is suddenly altered the gas will undergo a sudden contraction or expansion, owing to the change in pressure, and this will cause an alteration in the gas temperature. If it be assumed that the change takes place so quickly that it is adiabatic, it is possible to calculate the amount of superheating which will arise per thousand feet alteration in altitude.

Let suffix a refer to air and suffix g refer to the gas.

For adiabatic change PV^γ = a constant (γ = the ratio of the specific heats).

For unit weight of gas $V = 1/\rho$ (where ρ = the density).

$$\frac{P}{\rho^\gamma} = \text{a constant or } P^{1/\gamma}\left(\frac{1}{\rho}\right) = \text{a constant.}$$

$$P^{1/\gamma}\left(\frac{1}{\rho}\right) = P^{-(1-1/\gamma)}\,P/\rho = \text{a constant} \quad . \quad . \quad . \quad . \quad (1)$$

By the ordinary gas equation $P/\rho = RT$.

It therefore follows from (1) that $P^{\left(\frac{1-\gamma}{\gamma}\right)}RT = \text{a constant.}$

$$\therefore \frac{T}{P^{(\gamma-1)/\gamma}} = \text{a constant} = k.$$

$$\frac{\partial T}{\partial P} = k \cdot \frac{\gamma-1}{\gamma} \cdot \frac{P^{(\gamma-1)/\gamma}}{P} = \frac{\gamma-1}{\gamma}\,\frac{T}{P} \quad . \quad . \quad . \quad (2)$$

Let h refer to altitude $\dfrac{dT_g}{dh} = \dfrac{\partial T_g}{\partial P}\dfrac{\partial P}{\partial h}$

$\partial P/\partial h$ is the same for air and gas, and for the present purpose it is sufficiently accurate to assume that it equals $g\rho a$. Then from (2) it follows that

$$\frac{dT_g}{dh} = g\rho a \cdot \frac{\gamma-1}{\gamma} \cdot \frac{T_g}{P} = g\,\frac{\gamma-1}{\gamma}\,\frac{\rho_a T_a}{P} \cdot \frac{T_g}{T_a} (\gamma \text{ refers to the gas}).$$

$$\therefore \frac{dT_g}{dh} = \frac{g}{R_a} \cdot \frac{\gamma-1}{\gamma} \cdot \frac{T_g}{T_a} \left(\text{since } \frac{\rho_a T_a}{P} = \frac{1}{R_a}\right)$$

* The authors are indebted to Flight-Lieut. F. M. Rope for some of the information contained in this appendix.

Approximately $T_g = T_a$.

$$\frac{dT_g}{dh} = \frac{g}{R_a} \frac{\gamma - 1}{\gamma} \quad . \quad . \quad . \quad . \quad . \quad . \quad (3)$$

For hydrogen $\gamma = 1.419$.

For air $R_a = 3090$ (slugs – lbs. per sq. ft. – °C. abs. units).

$$\frac{dT_g}{dh} = \frac{32.2 \times .419}{3090 \times 1.419} = .003075°\text{C. per ft.}$$

$$\frac{dT_g}{dh} = \begin{cases} 3.075°\text{C. per 1,000 ft.} \\ 5.54°\text{F.} \quad ,, \end{cases}$$

This should be compared with the normal atmospheric temperature gradient of between 1.98 and 1.65°C. per 1,000 feet.

Some attempts have been made to check this calculation by experiments with R.33. The change in volume cannot, of course, be regarded as truly adiabatic, but the experiments demonstrate quite clearly that there is a change in the gas temperature caused by rapid change in volume when the altitude of the airship is quickly altered. The chief difficulty in making such experiments lies in separating the changes of gas temperature due to rapid alteration of altitude from those due to variation in external air temperature and to variation in the sun's intensity. The temperature measurements are subject to limitations, which have already been referred to.

TABLE 12.

EXPERIMENTS WITH R.33. 20/3/20.

Change of height in feet.	Change of Gas Temp. °F.	Change of Air Temp. °F.	Time Interval. Minutes.	Rate of ascent or descent. Feet/min.	Rate of change of Gas Temp. with height °F./1,000ft.	Remarks.
−4000	+15	+7½	17	−230	−3·75	—
−1400	+ 6	−1	5	−280	−4·3	—
+1400	− 6	−2	10	+140	−4·3	—
−1500	+11	+1½	16	− 94	−7·3	Slow descent.
−1750	+11	−3	6	−290	−6.3	Sun recently uncovered causing additional superheating.

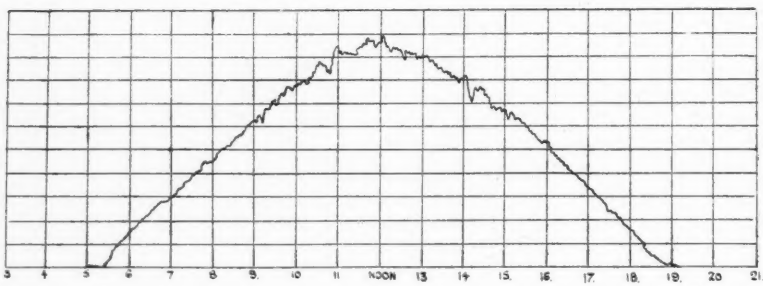
APPENDIX II.

Effect of Diurnal Variation of Solar Intensity on the Superheating of an Airship

The variation of solar intensity throughout the day may be represented by what is practically a sine curve with its maximum at noon. An actual example taken at South Kensington* is shown in Fig. 3. The nature of the variation with height is shown in Fig. 4. The curve of distribution over the day will have the same general form as that given in Fig. 3 for any height with a maximum at noon, although the actual ordinates will have different values. It is outside the scope of this paper to discuss the distribution of solar intensity at any great length, but reference may be made to the excellent literature on the subject.†

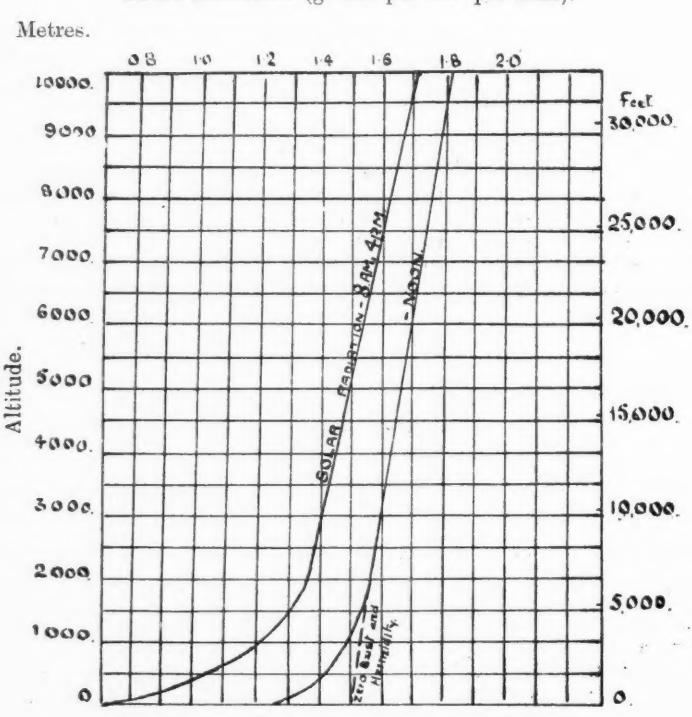
* R. Corless, Geophysical Memories No. 4.

† M. A. Baldit, Annales du Bureau Central Meteorologique de France, Part I., 1909.



Variations of Solar Intensity throughout the Day.
South Kensington, Friday, 1st September, 1911.

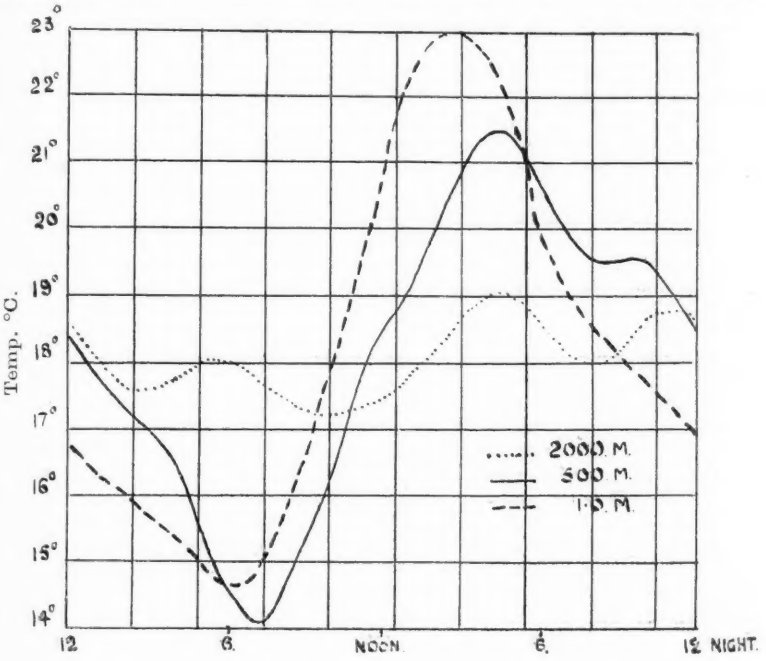
Fig. 3.



Variation of Solar Radiation with Height.

Fig. 4.

Since the air gains its heat by contact with the ground, there is necessarily a lag between the air temperature and the ground surface temperature, which latter practically follows the solar intensity. The hourly variation of the temperature of the air at different height has been carefully studied by H. Hergesell* at Lindenberg, and reference to his paper should be made for fuller information on the subject. The general form of the curves of variation of air temperature for different heights above Lindenberg are shown in Fig. 5, which represents



VARIATION OF TEMPERATURE AT DIFFERENT HEIGHTS THROUGHOUT THE DAY.

FIG. 5.

summer conditions. It will be seen that the maximum air temperature lags behind noon by about $2\frac{3}{4}$ hours at one metre above the surface, $4\frac{1}{2}$ hours at 500 metres, and $4\frac{3}{4}$ hours at 2,000 metres. It will be seen that the curves for the upper atmosphere exhibit interesting harmonics due to convection currents. The hourly variation of temperature at different heights in hot climates has not yet been studied in detail, but the range of temperature variation at one metre height which is shown as about 8°C. for Lindenberg would be about 12°C. for Cairo.† Hergesell's curves show that for a height of 2,000 metres and over the curves for different heights coincide fairly closely with one another and show a lag of the maximum of about $4\frac{3}{4}$ hours after noon. Now the heating of the fabric of an airship by the sun is analogous to the heating of the earth, and the heating of the gas in the airship by the fabric is analogous to the heating of the air by the earth if it is assumed that approximately the same relative amount of convection

* Die Arbeiten des Preussischen Aeronautischen, Observatoriums. XIV. Band, 1922.
† *Vide* Table 4.

takes place in both cases. There will be one difference, however—it will be seen that the air temperature curve is not symmetrical and the lower rate of cooling after the maximum is passed is probably due to stratification being set up. The gas temperature curve will probably be more symmetrical. The temperature of the gas will tend to lag behind that of the fabric in the same manner as the air temperature lags behind that of the earth. This lag will depend on the relation of the volume of the airship to its heating surface and hence will be roughly proportional to the lineal dimensions of the airship. It follows that the lag will be greater in large ships than in small ones. In very small airships the temperature of the gas follows the variation of sun intensity very quickly, and this is found to cause the lift to vary very rapidly. Edwards and Long* found that the mean temperature of the fabric in their small balloon followed the solar intensity very quickly and was always proportional to it.

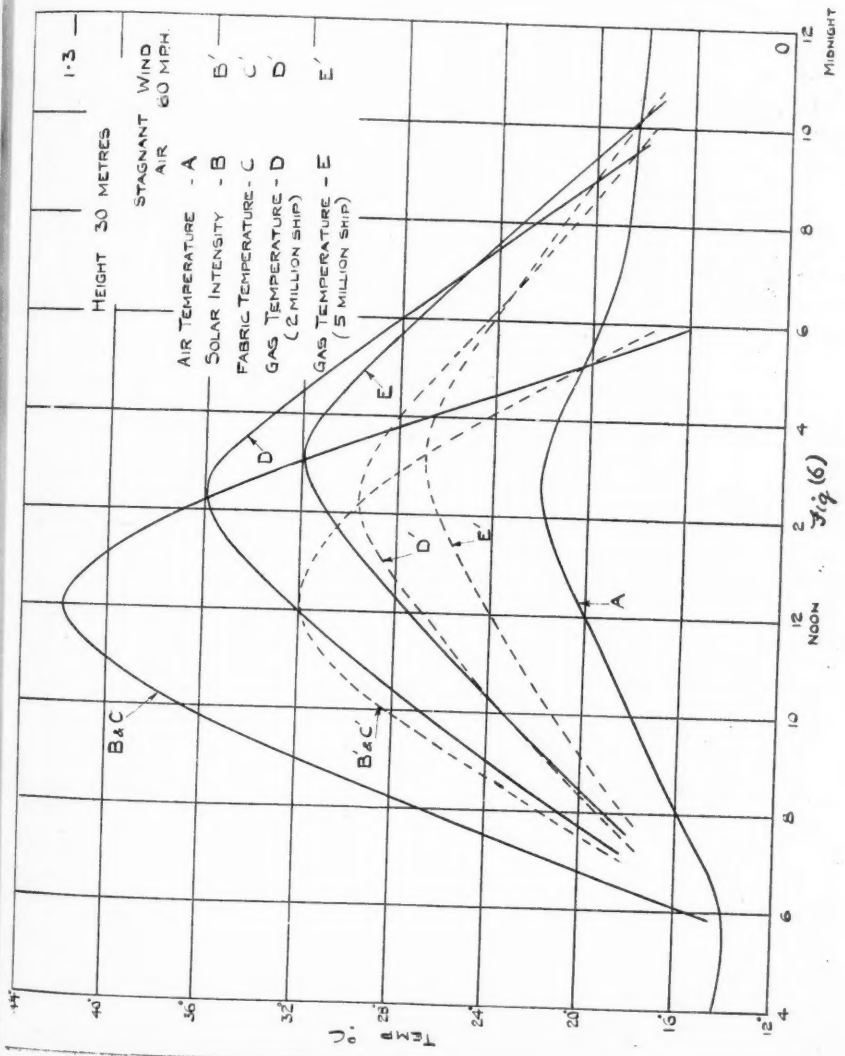
It is proposed to consider the case of an airship near the ground (say at a mast) when no wind is blowing. Curve A represents air temperature taken from Fig. 5. Curve B represents solar intensity taken from Fig. 3. Edwards and Long* have shown that an aluminium-coated fabric will attain a temperature of about 24°C. above that of the surrounding atmosphere when the sun's intensity is 1.4 grm. calories per sq. cm. per minute† Let it be assumed that the sun's intensity at noon near the ground is about 1.3 (*vide* Fig. 4); then the fabric temperature will be about 22°C. above that of the surrounding air. This enables the maximum of the curve (C) of fabric temperature to be fixed, and the curve is drawn into the same form as B for the reasons given above. For the sake of convenience the two curves have been made to coincide, and different scales are shown on opposite sides of the figure. Under these conditions the maximum possible superheating (which will only occur in a very small airship) is 22°C., but it will be seen that the lag of the gas temperature will reduce the maximum possible temperature of the gas, and the bigger the lag, the bigger this reduction will be. Curve D represents the probable variation of gas temperature for a ship of the R.33 class. It should be noted that the maximum of D will always come where D cuts C, since there can be no further heating of the gas after the fabric and gas temperatures have become equal. The maximum superheating experienced near the ground with R.33 has been found to be about 14°C. when no wind is blowing. It will be seen that this gives a lag of about 2.2 hours in the maximum, which agrees very well with actual experience. It will further be seen that there is no superheating at 9.30 p.m., which again agrees quite well with experience. On the assumption that the lag is proportional to the lineal dimensions, the lag in a 5,000,000 cub. ft. ship will be 1.35 times that in R.33 (2,000,000), *i.e.*, it will be 3.0 hours. This enables the gas temperature, Curve E, of such a ship to be drawn in with fair accuracy, from which it will be seen that the probable maximum superheating is about 10°C. for the conditions stated, which are summer time in England, close to the ground with no wind blowing and a clear sky. The effect of wind will be to modify these curves very considerably. Very little data has been obtained so far on which it is possible to estimate the effect of wind cooling, but an attempt has been made to do so in order to illustrate a possible method, rather than to give positive values. Experiments have been made at the National Physical Laboratory‡ to measure the rate of transmission of heat from the walls of an airship passenger car. The walls of the model consisted of aluminium doped fabric similar to that which would be used in the outer cover of a rigid airship. It was found that when a wind of 60 m.p.h. (which is the only speed it is proposed to consider here) was blowing over the surface of the car, the energy per sq. ft.

* *Loc. cit.*

† *Vide* Table 11.

‡ *Vide* Miss Dorothy Marshall. Reports of the Aeronautical Research Committee, No. T.169

of surface required to maintain 1°C. difference of temperature between the inside and the outside of the car was 1.5 watts more than the energy required when no wind was blowing. Cooling will be more efficient with a streamline body than with a cylindrical one. Hughes* has found that the ratio is about 1 to .85 if the two bodies have the same superficial area. If it is assumed that the model of the passenger car was roughly cylindrical, the figure of 1.5 watts would become 1.7 approximately for a streamline body. This is equivalent to .0247 grm. calories per sq. cm. per minute per degree difference of temperature between the inside



* *Vide* Phil. Mag. 31, p. 126, 1916.

and the outside. Now in these experiments heat was supplied to the air inside the model so that the temperature of the fabric was intermediate between the internal and external temperatures. In an airship heat is supplied to the interior and to the exterior by the fabric, which is therefore hotter than either. This makes a comparison difficult. For the want of fuller information it is assumed that the mean temperature of the fabric in the model experiments was exactly half-way between that of the interior and the exterior. This means that .0247 grm. calories per sq. cm. per minute were required to maintain a temperature difference of *half a degree* centigrade between the fabric and the air flowing over it. The

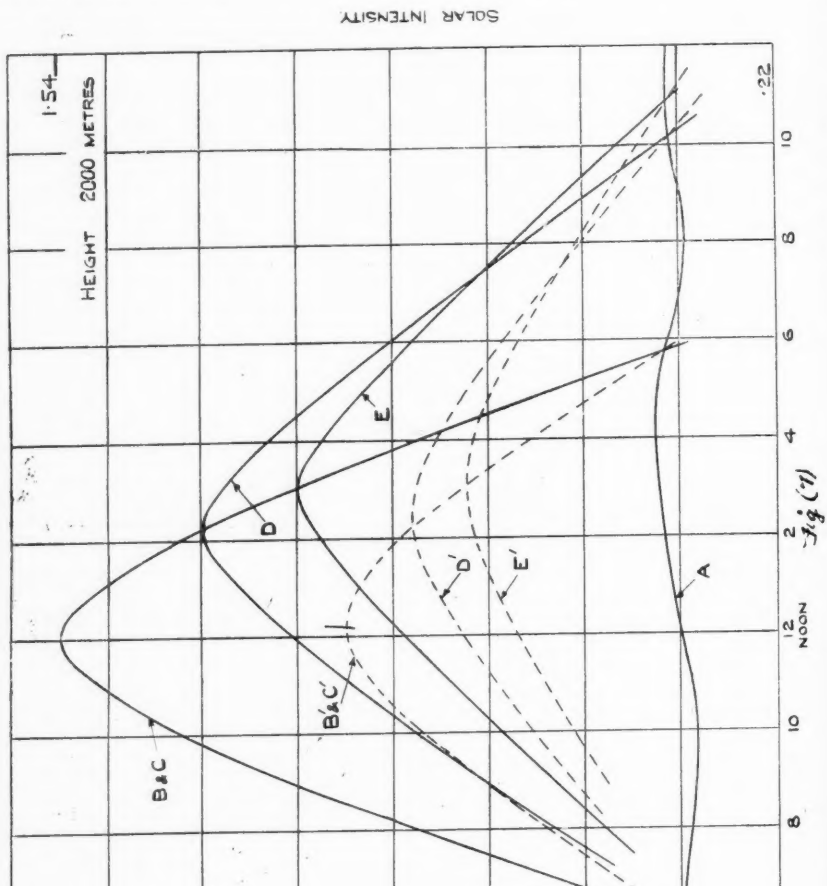


Fig. (11)

solar intensity value taken in Fig. 6 was 1.3 grm. calories per sq. cm. per minute, and the cooling effect may be considered as a virtual reduction of this. If the fabric temperature is taken as proportional to the virtual incident energy, then—

$$\frac{1.3 - 2 \times .0247\, x}{1.3} = \frac{x}{x_1}$$

x_1 = the temperature difference at noon between fabric and air with no wind.

x = the temperature difference at noon between fabric and air with a wind of 60 m.p.h.

x_1 has been taken as 22°C. This will give a value of 12°C. approximately for x when substituted in the above equation. This enables C^1, the new curve of fabric temperature, to be sketched in. If it be assumed that there is the same lag of gas temperature over fabric temperature as before (*i.e.*, that the lag is not affected by temperature difference between the two) the gas temperature curves D^1 and E^1 for a 2-million and a 5-million ship respectively can now also be sketched in. These indicate a maximum superheating of 7.8°C. for the 2-million ship and 5°C. for the 5-million ship approximately.

Fig. 7 exhibits similar curves for a height of 2,000 metres. The air temperature curve A is taken from Fig. 5 as before. The new value of solar intensity at noon for this height is found from Fig. 4 to be 1.54 grm. calories. The value of the superheating given by these curves will of course be higher than before. All the results are summarised in Table 13.

TABLE 13.

MAXIMUM SUPERHEATING (°C.).

Height (metres).	Condition.	2-million cu. ft. ship.	5-million cu. ft. ship.
30	Stagnant air.	14	10
2000		19	17
30	Wind 60 m.p.h.	7.8	5
2000		10	8

If it was desired to carry out similar calculations for tropical climates, the tables given by Baldit* could be used to find the solar intensity, but there is not sufficient data at present on the hourly variation of temperature at different heights in these localities.

If a harmonic analysis was made of the curves of sun intensity and air temperature it would be possible to treat the whole subject in a purely mathematical fashion. It is thought, however, that the foregoing graphical treatment is clearer and is certainly of a sufficient degree of accuracy for the data at present available. It is also felt that the assumptions which have been made are the best that the present state of our information will allow, but at the same time too much importance must not be attached to the absolute values which have to be obtained. Once the fundamental assumption (that the lag of gas temperature over fabric temperature is proportional to the lineal dimensions of the ship only) is allowed, it follows that false lift due to superheating will grow proportionately less with size and not greater, as appears to be believed in some quarters. What proportion of false lift can be dealt with by dynamic means is another question altogether, and has been dealt with in section (1*b*).

* *Loc. cit.*

APPENDIX III.

Humidity Correction to the Lift of an Airship

The pressure of water vapour in the atmosphere or in the gas will alter the density and hence will affect the lift of an airship. The equations which have been given for lift take no account of this. Let the pressure and temperature at sea level be denoted by P_Z and T_Z respectively, and let the relative humidity of the atmosphere be denoted by H_a. Let p_z be the tension of aqueous vapour which would exist if the air were saturated at temperature T_Z and let p_w be the actual tension of aqueous vapour when the relative humidity is H_a.

Then $\frac{p_w}{p_z} = H_a$* (all pressures to be expressed in millibars).

The value of p_z for various values of T_Z has been tabulated and hence it is possible to find p_w which equals $p_z H_a$.

If P_A be the partial pressure of the atmosphere P_Z equals $P_A + p_z H_a$. Let the absolute humidity (in lbs. per 1,000 cu. ft.) to saturate the atmosphere at temperature T_Z be A_Z. If A_w is the actual amount of water vapour present, then $A_w/A_z = H_a$.

The fundamental expression for the lift may be written in the form

$$\text{Lift} = \frac{\text{Tot. cap. (cu. ft.)}}{1{,}000} \times \text{percentage full at sea level}$$

$$\times (\text{wt. of } 1{,}000 \text{ cu. ft. of air} - \text{wt. of } 1{,}000 \text{ cu. ft. of gas}).$$

The gas may be impure and since the "purity" as commonly found is the ratio of the lift of impure gas to that of pure gas, it may be included as a multiplier in the above expression. This point will have to be considered in more detail later. Let it be assumed that the relative humidity of the gas is different from that of the air and has a value H_g.

$$\text{Weight of } 1{,}000 \text{ cu. ft. of air} = \left\{ 78.2 \left(\frac{P_z - p_z H_a}{T_z} \right) \frac{282}{1014} + A_z H_a \right\}$$

$$\text{Weight of } 1{,}000 \text{ cu. ft. of gas} = \left\{ 5.434 \left(\frac{P_z - p_z H_g}{T_z} \right) \frac{282}{1014} + A_z H_g \right\}$$

The difference of these two may be expressed in the form—

$$\frac{282}{1014} \left\{ (78.2 - 5.434) \frac{P_z}{T_z} - \frac{78.2\, p_z H_a}{T_z} + \frac{5.434\, p_z H_g}{T_z} \right\} + A_z (H_a - H_g)$$

$$= \frac{282}{1014} \left\{ (78.2 - 5.434) \frac{P_z}{T_z} - \frac{p_z}{T_z} (78.2\, H_a - 5.434\, H_g) \right\} + A_z (H_a - H_g)$$

$$= \frac{282}{1014} \left\{ 78.2 \times .9305 \times \frac{P_z}{T_z} - \frac{p_z}{T_z} (78.2\, H_a - 5.434\, H_g) \right\} + A_z (H_a - H_g)$$

If $H_a = H_g$ this expression simplifies to $\frac{282}{1014} \left\{ 78.2 \times .9305 \left(\frac{P_z - p_z H_a}{T_z} \right) \right\}$

Assuming for the moment that the gas is quite pure the expression for gross lift becomes

$$\text{Gross lift} = \frac{\text{total cap. (cu. ft.)}}{1{,}000}$$

$$\times \text{percentage full at sea level } (p_z,\ T_z) \times 78.2 \times .9305 \times \frac{P_z}{T_z} \times \frac{282}{1014}$$

$$- \frac{\text{total cap.}}{1{,}000} \times \text{percentage full} \left\{ \left[\frac{282}{1014} \frac{p_z}{T_z} (78.2\, H_a - 5.434\, H_g) \right] - A_z (H_a - H_g) \right\}$$

* This assumption is only approximate, but is accurate enough for all practical purposes. It is used by Eberhardt.

On comparing this with equation (4) it will be seen that the latter part of the expression represents the correction to be introduced for humidity.

If the purity could be measured with the gas at H_g relative humidity and the air at H_a relative humidity, then it might be included as a multiplier in both parts of the foregoing expression. Actually as measured in the Schilling Purity Meter both the gas and the air are practically saturated. To correct this to absolutely dry condition, as is recommended in certain places, would be equally faulty. If H_g and H_a are known and it is assumed that the gas and air are saturated in the Schilling meter it is not difficult to compute the correct purity to be included as a multiplier in the expression obtained above. The method is too lengthy to be set out here in detail. The method employed in Germany (*vide* C. Eberhardt, "Der Motorwagen," No. 13, May 11th, 1919) for reducing the lift of an airship to standard conditions is to use the Schilling meter directly for obtaining the ratio of gas density to air density. Since, as has been said, both air and gas become saturated in the meter, the ratio obtained in this manner is not quite correct.

If the gas temperature is not the same as the air temperature p_z and A_z will not be the same for both gas and air. For moderate superheating this difference may be neglected however and the full expression becomes:—

$$\text{Gross lift} = \frac{\text{total capacity (cu. ft.)}}{1{,}000} \times \text{percentage full (at } P_z T_z) \left\{ \text{purity} \times .9305 + \frac{T_g - T_a}{T_a} \right\} 78.2 \times \frac{P_z}{T_z} \times \frac{282}{1014} - \frac{\text{total capacity}}{1{,}000}$$

$$\times \text{percentage full} \left\{ \frac{282}{1014} \frac{p_z}{T_z} \text{purity } (78.2\, H_a - 5.43\, H_g) + \left(\frac{T_g - T_a}{T_a} \right) \frac{p_a}{P_a} \times \frac{282}{1014} - A_z (H_a - H_g) \right\}$$

REVIEWS

Elementary Aeronautical Science

By Ivor B. Hart and W. Laidler. (Clarendon Press, Oxford.) 288 pp. 7s. 0d. net.

A book of this kind has long been needed. The standard books are too lengthy and too difficult for the beginner and there has been no satisfactory elementary book to lead up to them. The subject is one, moreover, which it is difficult to write upon with the necessary lucidity and brevity without losing in accuracy of statement. The authors are part of the Civilian Educational Staff of the Royal Air Force; a staff which necessarily monopolises experience in teaching aeronautical science to large classes in this country. This experience is made use of in the book which forms the subject of this review.

Knowledge of the subject is a basic essential, wisdom in handling it is more difficult to attain; the authors with their almost unique opportunity of discovering what is needed, and of avoiding pitfalls, have had the advantage, of which they make full recognition, of advice from Colonel Curtis, the Adviser on Education at the Air Ministry, and from others connected with the Air Service.

The book is divided into three parts of which the first is a brief introduction to the subject, followed by a section on the elementary principles of flight with chapters on the aerofoil, the lift-drag ratio, stability, and control and manœuvre. The third, and longest, section relates to the structure of the airplane and has chapters on the airscrew, bending moments, etc., materials, various airplane parts, aero instruments and the aero engine. A convenient number of examples are scattered through the book and their solutions given. (It is a little unfortunate perhaps that one of the first problems should lay bare the effect of a vertical crash at 50 m.p.h. !)

That part of the book dealing with inherent stability is of especial interest. It is a vitally important part of the subject and, as usually presented, bristles with difficulties. It is impossible to treat it, of course, without mathematical analysis if any detailed attention is to be given to the matter; but the authors show most praiseworthy skill in presenting a useful and logical statement of the methods of attaining stability in language which can be easily followed and with the veriest minimum of computation.

The book may be safely recommended to young airmen.